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ON SOME OF THE

PHENOMENA OF NEW STARS.

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SOLAR PHYSICS COMMITTEE.

ON SOME OF THE

PHENOMENA OF NEW STARS.

UNDER THE DIRECTION OF

Sir NORMAN LOCKYER, K.C.B., LL.D., D.Sc., F.R.S.

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Report by the Committee on Solar Physics	(1882)
Second Report of the Committee on Solar Physics	(1889)
Positions and Areas of Sun Spots and Faculæ, 1887–88	(1889)
" " " " " " " " 1889	(1891)
" " " " " " " " 1878–1881 (inclusive) and 1890	(1892)
" " " " " " " " 1891	(1894)
" " " " " " " " 1892	(1895)
" " " " " " " " 1893	(1896)
" " " " " " " " 1894, 1895, 1896 and 1897	(1899)
Spectra of Sun Spots 1879–1897 (inclusive)	(1900)
Positions and Areas of Sun Spots and Faculæ, 1898 and 1899	(1901)
Catalogue of 470 of the Brighter Stars Classified according to their Chemistry	(1902)
The Sun's Spotted Area, 1832–1900	(1902)
Positions and Areas of Sun Spots and Faculæ, 1900, 1901 and 1902	(1904)
Mean Annual Variations of Barometric Pressure and Rainfall	(1905)
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" " " " " " " " 1909	(1911)
" " " " " " " " 1910	(1911)
Report of the Solar Eclipse Expedition to Vavau, Tonga Islands, April 29, 1911 (Eastern Date)	(1912)
(I) On the Spectra of the Rigelian, Crucian and Alnitamian Stars ; (II) The Line Spectrum of α Orionis ; (III) The Spectrum of γ Cassiopeiæ (one volume)	(1914)
Areas of Calcium Flocculi on Spectroheliograms, 1906–08	(1914)
On Some of the Phenomena of New Stars	(1914)

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LIST OF ILLUSTRATIONS.

PREFACE.

The materials for this memoir have been accumulating for many years, indeed since my papers on Nova Persei communicated to the Royal Society in 1901–02.

Mr. Rolston has recently been employed on them, under my supervision, because I was anxious to bring them together before my work here ceased.

Very fortunately, while this was going on, Professor Iniguez, of the Astronomical and Meteorological Observatory, Madrid, was good enough to send me a most valuable series of photographs of the spectrum of the recent nova, taken by him, with full permission to reduce them. This reduction has been made by Mr. Baxandall with great care, and I think it is clear that the Madrid results afford a most valuable comparison with, and confirmation of, those obtained from other novæ. They also enable the sequence of the phenomena to be studied with greater precision than was possible before.

It was my original intention that this memoir should be more comprehensive than it is, *e.g.*, there is the large question of the nebulosity connected with novæ, as in the case of Nova Persei (2), but the pressure of work incident upon the removal of the Observatory has made a complete discussion impossible. The general conclusions to be derived from the collection of data now brought together must therefore be deferred to a further memoir.

NORMAN LOCKYER.

Solar Physics Observatory,
South Kensington.
March 17, 1913.

1.—ON THE SPECTRA OF NEW STARS.

Introduction.—This memoir is a continuation of that which I communicated to the Royal Society in 1890* on the causes which produce the phenomena of new stars.

Up to that time the observations of novæ had been visual. In the first memoir an account was given of the various theories from those of Tycho Brahe and Kepler, which had been put forward to explain the sudden increase of light. I was the first in 1877 to ascribe it to meteoric collisions,† and the fading away to a backwardation due to a reduction of temperature of the phenomena seen in stars increasing their temperature.

This memoir also contained and discussed the eye observations made up to that time.

In the present memoir I propose to discuss the spectra obtained by the photographs taken in later years, the first dating from 1892, when a nova made its appearance in the constellation Auriga.

The following table gives the names and the dates of discovery of the various objects. In the first column are given the dates of discovery of the nova named in the second column. In the third, fourth, and fifth columns the dates of the first observation are recorded and show in each case whether the observation was made visually, photographically, or spectroscopically. The sixth column gives the date that the apparition of the nova was discovered, and except in the case of the visual observations this need not necessarily coincide with the date of the first observation, for in the case of the photographic observations, direct or spectroscopic, the plate was sometimes not examined until some months after it was taken; the name of the discoverer is given in the seventh column. The eighth column gives the magnitude at the time of discovery.

TABLE I.

PARTICULARS CONCERNING THE NOVÆ DISCOVERED SINCE 1891.

Number.	Year announced.	Name.	R.A. (1900.)	Dec. (1900.)	Date first observed			Discoverer.	Magnitude at Time of Discovery.
					Visually.	Photographically.	Spectroscopically.		
			H. M.	° ′					
1	1892	N. Aurigæ - -	5 25·6	30 22 N.	1.2.92	10.12.91	—	Anderson -	4·4
2	1893	N. Normæ - -	15 22·2	50 14 S.	—	—	10.7.93	Fleming -	7·0
3	1895	N. Centauri -	13 34·3	31 8 S.	- -	8.7.95	18.7.95	Fleming -	7·2
4	1896	N. Carinæ - -	11 3·9	61 24 S.	—	8.4.95	14.4.95	Fleming -	8·0

* Phil. Trans., 182A, p. 397.

† Nature, 16, p. 413; reprinted Phil. Trans., 182, p. 405.

PARTICULARS CONCERNING THE NOVÆ DISCOVERED SINCE 1891—*continued.*

Number.	Year announced.	Name.	R.A. (1900.)	Dec. (1900)	Date first observed. Visually.	Photographically.	Spectroscopically.	Discoverer.	Magnitude at Time of Discovery.
			H. M.	° ′					
5	1899	N. Sagittarii (1)	18 56·2	13 18 S.	—	8.3.98	19.4.98	Fleming	4·7
6	1900	N. Aquilæ (1)	19 15·3	0 19 S.	—	21.4.99	3.7.99	Fleming	7·0
7	1901	N. Persei (2)	3 24·4	43 34 N.	22.2.1901	22.2.1901	22.2.1901	Anderson	2·7
8	1903	N. Geminorum (1)	6 37·8	30 3 N.	—	16.3.03	26.3.03	Turner	8·0
9	1905	N. Ophiuchi (3)	17 44·8	16 40 S.	—	1888	15.7.98	Fleming	7·7
10	1905	N. Aquilæ (2)	18 56·8	4 35 S.	—	—	18.8.05	Fleming	9·0
11	1906	N. Scorpii (2)	17 47·5	34 20 S.	—	14.6.06	—	Cannon	8·8
12	1906	N. Velorum	10 58·3	53 51 S.	—	5.12.05	—	Leavitt	9·7
13	1907	N. Circini	14 40·5	59 35 S.	—	.2.06	—	Leavitt	9·5
14	1910	N. Aræ	16 33·0	52 14 S.	—	4.4.10	5.7.10	Fleming	6·0
15	1910	N. Sagittarii (2)	17 53·8	27 33 S.	—	31.5.10	21.3.10	Fleming	7·8
16	1910	N. Sagittarii (3)	18 13·8	25 14 S.	—	10.8.99	—	Cannon	8·5
17	1910	N. Lacertæ	22 31·8	52 12 N.	30.12.10	19.11.10	1.1.11	Espin	8·0
18	1911	N. Sagittarii (4)	18 0·5	27 26 S.	—	22.5.01	—	Cannon	10·3
19	1912	N. Geminorum (2)	6 48·4	32 16 N.	12.2.12	13.2.12	—	Enebo	4·5

In the case of a number of these novæ, the star was too faint when discovered for its spectrum to be secured, in other cases the spectrum which revealed its nova character was insufficient to give much more information; it will therefore be impossible to include the objects in the discussion. On these grounds Nos. 11, 13, 16, 17 may be dismissed at once.

2.—THE SPECTRA OF THE FAINTER NOVÆ.

We have some spectroscopic data for N. Aurigæ (1892), N. Normæ (1893), N. Carinæ (1896), N. Centauri (1895), N. Sagittarii (1) (1899), N. Ophiuchi (1898), N. Aquilæ (1) (1899), N. Persei (2) (1901), N. Geminorum (1) (1903), N. Aquilæ (2) (1905), N. Velorum (1906), N. Sagittarii (2) (1910), N. Aræ (1910), N. Lacertæ (1910), and N. Geminorum (2) (1912). In four cases only, viz., N. Aurigæ, N. Persei, N. Lacertæ and N. Geminorum (2) are the data full enough to warrant detailed discussion, and these four will be discussed later. N. Centauri, although providing meagre data, appears to have presented special features calling for further remark, but for the present we will dispose of the remaining ten by tabulating the lines recorded in their spectra.

TABLE II.

SPECTRA OF THE FAINTER NOVÆ.

Nova Normæ. 1894, Feb. 13.	Nova Carinæ. 1895, April 14.	Nova Sagittarii (1). 1898, April 19.	Nova Ophiuchi (2), (R.S. Ophiuchi).§ 1898, July 15.	Nova Aquilæ. 1899, July 3.‖	Nova Geminorum (1). 1903, April 2.	Nova Aquilæ (2). 1905, Aug. 18.¶	Nova Velorum. 1906, June 6.	Nova Sagittarii (2). 1910, Mar.-June.	Nova Aræ. 1910, July 5.
—	—	—	—	—	λλ 335	—	—	—	—
—	—	—	—	—	350	—	—	—	—
—	—	—	—	—	374	—	—	—	—
—	—	H_η	—	—	384	—	—	383	383
—	H_ζ	H_ζ	H_ζ (2)	H_ζ	389	—	—	3889	3889
—	H_ϵ	H_ϵ	H_ϵ (1)	H_ϵ	397	—	—	3970	3970
—	—	4029	—	—	—	—	—	—	—
—	H_δ	H_δ	H_δ (5)	H_δ	410	4101	4101	4101	410
—	—	4179	—	—	—	—	—	—	—
—	—	4238	—	—	—	—	—	—	—
—	—	4276	—	—	—	—	—	—	—
—	H_γ	H_γ	H_γ (10)	H_γ	434	4341	4340	4341	4341
—	—	4459	—	—	446	—	—	—	—
—	—	—	—	—	—	4472	—	—	—
—	—	4530	—	—	—	—	—	—	—
—	—	—	—	—	—	—	4611	—	—
—	(4700)†	4643	4656(7)	—	462	4646	4643	—	4670
—	—	—	4691(14)	4693	—	—	—	—	—
486	H_β	H_β	H_β (20)	H_β	486	4861	4862	4861	4861
—	—	4926	—	—	—	—	4926	—	—
4953	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	5003	—	—
—	—	‡(5005)	—	5007	—	—	5007	—	5007
*5013	—	—	—	—	—	—	5013	—	—
5175	—	—	—	—	—	—	—	—	—
Astron and Astro-Physics, Vol. XIII., p. 311 (Campbell).	Harv. Coll. Obs., *Circular* No. 1.	Harv. Coll. Obs., *Circular* No. 42.	Harv. Coll. Obs., *Circular* No. 76.	Harv. Coll. Obs., *Circular* No. 56 (Pickering).	Lick Obs., *Bulletin* No. 37, p. 298 (Perrine).	Harv. Coll. Obs., *Circular* No. 106.	Harv. Coll. Obs., *Circular* No. 121.	*Astronomische Nachrichten*, No. 4448.	Harv. Coll. Obs. *Annals*, Vol. LVI., Part VI., p. 170.

* Brightest line in the spectrum on March 6, 1894; measured wave-length 5007·3.

† Line about λ 4700 barely visible on April 14 was as bright as hydrogen lines on June 15, continuous spectrum very faint.

‡ 5005 appeared on April 21, 1898.

§ Variable. Observed at Harvard since 1888. On August 28, 1894, spectrum was K (Arcturian-Aldebarian) type without trace of bright lines.

‖ September 7, 1899, H_γ and λ 4959? and on October 27, 1899, H_γ and λ 5007 alone visible.

¶ Spectrum like that of Nova Persei on March 30, 1901. (Harv. Coll. Obs. Annals, Vol. LVI., Part VI., p. 170.)

Of the nova which appeared in the constellation Centaurus in 1895, Pickering stated* that the spectrum on July 18, 1895, resembled that of the nebula surrounding 30 Doradus, and was unlike that of an ordinary nebula or of the new stars in Auriga, Norma and Carina. According to Le Sueur†, the spectrum of 30 Doradus, examined with the great Melbourne reflector, showed the first nebular line 500 easily and the 497 line certainly but with difficulty, while the hydrogen line F was only suspected.

On December 16 and 19, continues Pickering, Mr. Wendell found the spectrum of the nova to be monochromatic and very similar to the adjacent nebula N.G.C. 5253.

The spectrum of this nova was examined by Prof. Campbell at Mount Hamilton on December 22 and 29, 1895, and seemed to him‡ to be continuous, certainly not nebular.

Re-examining it on February 8, 1896, under much better conditions, he found that the spectrum of the nova certainly was continuous although very peculiar. The maximum visual intensity was in the yellow-green, the green-blue was very faint, while the blue was surprisingly strong, in fact was very much brighter visually than the green-blue, and the spectrum was relatively faint about λ 5200 to λ 4600.

There was no trace of the nebular lines or of the H_β line, although there was some evidence of bright lines or of irregularities in the brightest portion of the spectrum, but the light was too weak to enable this to be established with certainty.

Prof. Campbell suggests the possibility that under the difficult conditions of the Harvard observations the spectrum of the neighbouring nebula, in which he finds the nebular lines with their usual intensities, was observed.

While there was a difference of opinion as to the inclusion of this object as a nova, it is now generally accepted as such, and we must consider it as a new star which exhibited a continuous spectrum. Subsequent observations by Prof. Hussey, quoted by Campbell,§ showed the star to be surrounded by a faint irregular nebulosity which was joined up to the adjacent large nebula N.G.C. 5253; this was on July 9, 1896, when the nova's magnitude was about 16.

3.—THE SPECTRA OF THE BRIGHTER NOVÆ.

(*a*).—THE SEQUENCE OF THE APPEARANCE OF DIFFERENT TYPES OF LINES.

We are now left to deal with the four objects named in the preceding section which have been sufficiently bright to afford spectra from which the information concerning the physical conditions of the radiating and absorbing matter involved could be deduced.

* Harvard College Observatory Circular No. 4.

† Proc. Roy. Soc., Vol. 18, p. 222.

‡ Astrophysical Journal, Vol. V., No. 4, p. 233.

§ *Ibid*, p. 234.

Among the facts noted in the study of these bodies is that the initial spectra differ; in some the spectrum is continuous, in others it is crossed with dark lines. In either case the spectra change and the change occurs more or less with the brilliancy of the novæ.

In order to be in a position to discuss the significant changes, we now proceed to give the available data concerning each spectral stage, reserving to a later section the general discussion of certain exceptional features in the separate stages.

So far as our knowledge extends at present, there are four distinct stages in the history of a nova as pictured in its spectrum :—

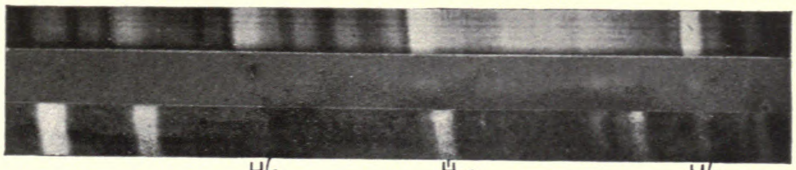
(1) A continuous spectrum stage in which in some cases dark lines are also observed as in the spectrum of a normal star;
(2) The bright line or "typical nova" stage where the outstanding feature is a spectrum crossed by broad bright bands;
(3) A stage marked by the presence of a line at about λ 4640; and
(4) A "bright band" or nebular stage where the continuous spectrum is absent or exceedingly faint and the bright lines first seen are replaced by others characteristic of the spectra of nebulae.

These stages we are about to study *seriatim*, but it must first be pointed out that one more has been reported to exist in the history of novæ succeeding (4); it is represented by a continuous spectrum. On August 30, 1903, the Lick* observers found that the chief nebular line had disappeared from the spectrum of Nova Aurigæ, a continuous spectrum alone remaining; further observations indicated that the spectra of Nova Persei (2) and Nova Geminorum (1) also showed the same tendency to become continuous.

In Table III. we give some indication of the epochs in the life of each nova at which the various changes have been observed.

NOVA PERSEI (2). S. KENSINGTON.

STAGE.
"BRIGHT-LINE"
"λ 4640"
"NEBULA."



TYPICAL SPECTRA AT VARIOUS STAGES.

FIG. 1.

The accompanying illustration (Fig. 1) gives examples of the photographic spectra during the "bright-line," the "4640" and the "nebula" stages as typified in Nova Persei.

* Lick Observatory, Bulletin No. 48.

TABLE III.

EPOCHS AT WHICH THE VARIOUS SPECTRAL CHANGES HAVE BEEN OBSERVED TO TAKE PLACE IN THE SEVERAL NOVÆ.

Nova.	Date of First Photographic or Visual Observation.	Date of Maximum Brightness.	Continuous Spectrum Observed.	Dark Line Spectrum Observed.	Bright Line Spectrum Observed.	λ 4610 Line predominant.	Nebular Spectrum Observed.
Aurigæ, 1892	Feb. 1, 1892	Feb. 3, 1892	—	—	Feb. 3, 1892 (South Kensington).	—	Aug. 17, 1892 (Campbell).
Persei (2), 1901	Feb. 22, 1901	Feb. 23, 1901	Feb. 22, 1901 (Edinboro').	Feb. 22, 1901 (Harvard).	Feb. 24, 1901 (Harvard).	Mar. 21, 1901 (South Kensington).	July 9, 1901 (Lick).
Geminorum (1), 1903	Mar. 16, 1903	Mar 6, 1903	—	—	—	Mar. 28, 1903 (Frost).	—
Lacertæ, 1910	Dec. 30, 1910	Jan. 2, 1911	—	—	Jan. 3, 1911	Mar. 30, 1911 (Wright).	—
Geminorum (2), 1912	Mar. 12, 1912	Mar, 14, 1912	—	Mar.13,14,1912 (Harvard).	Mar. 15, 1912 (Harvard).	Mar. 27, 1912 (Madrid).	April 6, 1912 (Mt. Wilson).

NOTE.—These dates, and therefore the intervals, are by no means rigid, because, in the first place, the change is a gradual one, difficult to determine, and, secondly, the time when such a change was first observed was not necessarily the actual time of its inception.

---

3 (*b*).—THE CONTINUOUS SPECTRUM, WITH OR WITHOUT DARK LINES, FIRST OBSERVED.

In 1901, when Nova Persei (2) appeared, Dr. Copeland examined the spectrum about 16 hours after the discovery of the nova, and found it to be strong and purely continuous.* When the discovery was generally known and weather permitted observations to be made this phase of the spectrum had disappeared, and, so far as we know, it has not been observed in the case of any other nova with the exception of the peculiar Nova Centauri referred to in the previous section. In the case of Nova Persei (2) dark absorption lines appeared within a few hours in the continuous spectrum.

Of the novæ discovered since 1891 it has been definitely recorded of two only that a purely dark (absorption) line spectrum stage has preceded that stage in the spectral changes in which the spectrum is essentially one of bright lines or bands, and is generally known as the "typical nova" spectrum. The two stars are Nova Persei (2) and Nova Geminorum (2).

* Pro. Roy. Soc., Edinburgh, Vol. XXV., Part I., p. 545, § 1.

The small proportion of novæ in which this stage has been observed is not surprising, for even in the two cases named the condition was remarkably transient, lasting but a few hours,* and those few hours would occur when observers were likely to be in a state of hurried preparation. Further, many of the remaining novæ were not recognised as such until months after they had been recorded by photography, and the Harvard plates on which they were recorded are of too small a dispersion to give any indications on such a fine point.†

Possibly such a stage was recorded by Huggins in the nova of 1866, Nova Coronæ, but his statement‡ is not very definite.

In the first place, the absorption spectrum was contemporaneous with the bright line spectrum and therefore is on a different basis to the purely absorption spectra recorded by Pickering in the later novæ.

The statement made by Huggins goes no further than to say that in general features, *i.e.*, in the breadth of the absorption lines and in the absence of hydrogen absorption, the spectrum resembles α Orionis (Antarian). Such a statement made in the early infancy of spectroscopy affords too weak a basis for us to class the Huggins absorption spectrum of Nova Coronæ with those purely dark-line spectra observed in the later novæ by Prof. Pickering.

Reverting to the consideration of these, we find that in the case of Nova Persei (2), Pickering described the spectrum in general terms as similar to that of Rigel,§ and that of Nova Geminorum (2) as similar to Procyon.‖ As these are two type-stars in the Kensington classification it will be convenient here to show their position in that classification where an attempt has been made to trace out, more or less consecutively, the life history of the stars, not merely to pigeon-hole them with labels having but little reference to their state of condensation or any scheme of evolution. Thus, we consider the Antarian class (*e.g.*, α Orionis) as the earliest known form of star, which later, by contraction, becomes hotter and hotter until the Argonian stage is reached, and then by excess of radiation, cools down through the various stages, including that to which the sun belongs, to the oldest known stellar type, the Piscian. Our diagram (Fig. 2) shows this graphically, as well as the change of condensation and the different conditions on each arm of the temperature curve. For each stage the Harvard designations of Miss Maury (M) and Miss Cannon (C) are given above and below, respectively, the Kensington name.

* Harvard Coll. Obs. Annals, Vol. LVI., No. III., p. 44.

† *See* Prof. E. C. Pickering, Ast. Nach.

‡ Proc. Roy. Soc., Vol. XV., p. 147, 1866.

§ Harvard Coll. Obs. Annals, Vol. LVI., No. III., p. 41.

‖ Harvard Coll. Obs. Circ. No. 176, p. 2.

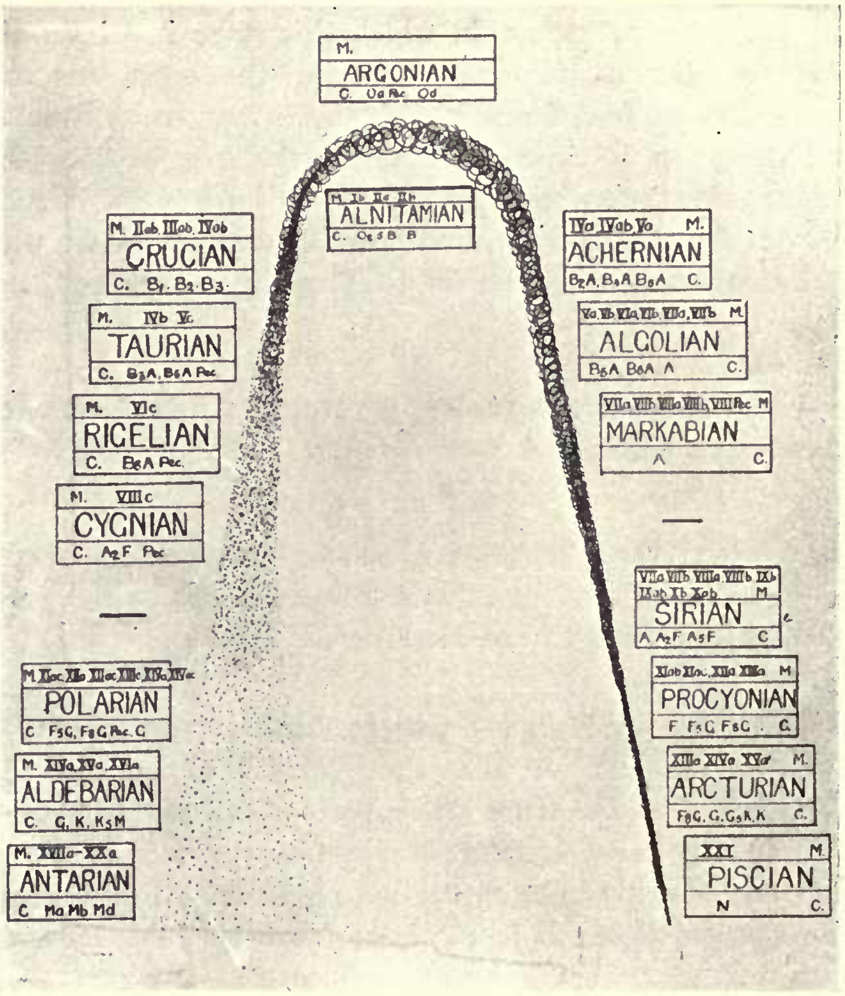


FIG. 2.—THE STELLAR CLASSIFICATION.

In the accompanying table (IV.) the dark lines observed photographically in N. Persei, at the Harvard College Observatory, on February 22, 1901, are compared with the dark lines of the type-stars Rigel, Bellatrix, Markab, and α Cygni; where two wave-lengths are given without a bracket, the lower one represents a line in a S. Kensington type-star. Pickering gave the spectrum at this time as similar to that of Rigel. *See* Plate I.

The following analysis of the lines in detail will enable us to study this question:—

The first two lines common to Nova Persei and the other spectra are due to hydrogen, and need no further remark.

4026·4 (3) Helium line. Comparatively weak in the nova (3 on a maximum of 40), and is therefore more like Markab (intens. 1–2 on maximum of 10) or α Cygni (intens. 1 on maximum of 10).

4076·9 (2) In Rigel and Bellatrix this is probably due to oxygen, the other
(4076·3)
oxygen lines near by being present. But in the nova this is the only oxygen line of the group that is possibly represented, and its oxygen origin seems to be unlikely.

TABLE IV.

COMPARISON OF THE "DARK LINE" SPECTRUM OF NOVA PERSEI GIVEN BY PICKERING WITH LINES IN THE SPECTRA OF S. KENSINGTON TYPE STARS.

Nova Persei. Pickering's Absorption Spectrum, Feb. 22, 1901.			Rigel. S. Kensington.		Bellatrix, S. Kensington.		Markab, S. Kensington.		α Cygni, S. Kensington.		Origins in Type-Stars.
λ λ Negative (1)	λ λ Negative (2)	Int. Max. =40.	λ λ	Int. (10)	λ λ	Int. (10)	λ λ	Int. (10)	λ λ	Int. (10)	
3893·6	—	15	3889·1	10	3889·1	10	3889·1	8	3889·1	10	H_ζ
3970·2	3970·2	25	3970·2	10	3970·2	10	3969·5	10	3970·2	10	H_ϵ
4026·4	4026·4	3	4026·3	5–6	4026·3	8	4026·3	1–2	4026·3	1	He
4076·9	—	2	4076·3	<	4076·3	2	—	—	—	—	O
—	—	—	—	—	—	—	4077·9	1	4077·9	3	p. Sr
4101·7	{4093·8 4102·8 4107·3}	30	4101·8	10	4101·8	10	4101·8	10	4101·8	10	H_δ
4126·4	—	7	4128·1	5	4129·1	1	4128·1	2	4128·1	5–6	p. Si (II.)
4151·1	4159·1	1	{4153·0 —	1–2 —	— 4154·0	— 2	— —	— —	— —	— —	— O
4266·4	4266·1	2	4267·5	3–4	4267·5	3	—	—	4267·5	<1	p. C.
4340·7	{4334·1 4340·7 4346·3}	40	4340·7	10	4340·7	10	4340·7	10	4340·7	10	H_γ
4365·5	4366·4	1	—	—	—	—	—	—	4365·4	<1	p. Mn ?
4388·4	4388·6	3	4388·1	3–4	4388·1	6	—	—	4388·1	1	Ast.
4415·3	—	1	—	—	4415·7*	2	—	—	4415·3	<1	Fe
—	—	—	4417·0	1	4417·2*	2 {	{4417·0 4417·9}	2–3	{4417·0 4417·9	5 2–3	p. Fe p. Ti
4434·6	4434·0	1	4437·7	1	4437·6	3	—	—	4434·4	1	Ast. Unk.
4470·1	4469·9	1	4471·6	6	4471·6	8	4471·6	1	4471·6	1–2	He
4480·7	{4474·9 4481·6 4487·2}	20	4481·3	7	4481·3	4	4481·3	6	4481·3	8	p. Mg.
4509·9	4511·2	2	4508·5	1	—	—	4508·5	1–2	4508·5	5	p. Fe
4529·5	4528·1	2	—	—	4529·6	1	—	—	4529·6	1	— p.Ti
—	4549·2	—	—	—	—	—	4549·8	3	—	—	{p. Fe p. Ti

* ? O in Bellatrix.

COMPARISON OF THE "DARK LINE" SPECTRUM OF NOVA PERSEI, &c.—*continued.*

Nova Persei. Pickering's Absorption. Spectrum, Feb. 22, 1901.			Rigel. S. Kensington.		Bellatrix. S. Kensington.		Markab, S. Kensington.		α Cygni, S. Kensington.		Origins in Type-Stars.
λ λ Negative (1)	λ λ Negative (2)	Int Max. = 40.	λ λ	Int. (10)	λ λ	Int. (10)	λ λ	Int. (10)	λ λ	Int. (10)	
4552·4	—	2	4552·8	1	4552·8	3	—	—	4552·8	<1	p. Si (III.)
—	—	—	4568·0	<1	4568·0	2	—	—	4568·0	<1	p. Si (III.)
4571·9	—	1	—	—	4570·4	1	—	—	4570·6	<1	—
—	—	—	—	—	—	—	4572·2	1	4572·2	4	p. Ti
4615·4	—	1	—	—	—	—	—	—	4616·8	2	p. Cr
4642·7	4642.2	2	4642·5	1	4640·1	1	—	—	4641·4	<1	—
4665·0	4661·1	4	—	—	—	—	—	—	4665·5	<1	—
4713·7	4714·4	3	4713·3	3	4713·3	4	—	—	—	—	He
—	4739·5	1	—	—	—	—	—	—	—	—	—
4861·5	(4854·7 {4861·5} (4867·9	40	4861·5	10	4861·5	10	4861·5	10	4861·5	10	H_β
4885·2	—	2	—	—	—	—	—	—	4884·3	1–2	p. Cr
—	4913·7	1	—	—	—	—	—	—	—	—	—
4922·2	—	2	4922·1	5	4922·2	5	—	—	—	—	Ast.
—	—	—	—	—	—	—	—	—	4924·1	8	p. Fe
—	—	—	—	—	5015·7	3	—	—	—	—	Ast.
—	5019·4	1	5018·6	5	—	—	—	—	—	—	p. Fe
5325·2	—	1	—	—	—	—	—	—	—	—	—
5399·2	5393·5	1	—	—	—	—	—	—	—	—	—
5431·9	5429·2	1	—	—	—	—	—	—	—	—	—
—	5455·3	1	—	—	—	—	—	—	—	—	—
—	5634·8	1	—	—	—	—	—	—	—	—	—
—	5663·2	1	—	—	—	—	—	—	—	—	—
5677·1	—	2	—	—	—	—	—	—	—	—	—
5695·2	5693·3	6	—	—	—	—	—	—	—	—	—
5719·3	5717·6	5	—	—	—	—	—	—	—	—	—
5761·2	5758·0	1	—	—	—	—	—	—	—	—	—

4128·1 (7). A Si. line (p. Si II. 4128·1) is near this position, but as the companion 4131·1 is not in the nova spectrum the p. Si origin must be abandoned.

4151·5 (1). In Bellatrix 4150·5 is ascribed possibly to N, but the other N lines are present, whereas in the nova spectrum they are not. Again the likeness to the type-star breaks down.

4266·4 (2). In Rigel and Bellatrix the line at λ 4267·5 is p.C. As (4267·5)
Asterium and Helium, elements usually associated with Carbon I., are present, there is nothing beyond the divergence of wave-length and possibly the absence of N to dismiss p.C as a possible origin. In the nova it is weak (2 on a scale of 40), and is therefore more like Bellatrix or Alnitam than Rigel.

4366·4 or 4365·5 (1). The only representative in the type-stars is a very weak line, ascribed to p.Mn, in α Cygni.

4388·1 (3). In Rigel and Bellatrix this is ascribed to Asterium, and at first sight one would accept this origin for the nova line. But 3964·9, 4009·4, 4143·9, as strong, or stronger, in the other stars, as well as other, weaker lines, are not shown in the nova spectrum. Of the 11 Asterium lines occurring in Bellatrix, only two, 4388 and 4922, are possibly represented in the nova spectrum.

There are only three Asterium lines possibly represented in the S. Kensington spectrum of α Cygni, and one of these is 4388·1, but 4922 is not in α Cygni, while the other two Asterium lines in the spectrum of that star do not appear in the nova spectrum.

We must conclude that the presence of Asterium in the nova is open to grave doubt.

4415·3 (1), 4434·6 (1). In Bellatrix these weak nova lines are ascribed to oxygen and nitrogen respectively, but in the nova many other oxygen and nitrogen lines are absent, and the oxygen and nitrogen origins are not tenable.

4470·1 (1), 4471·6. In Rigel the intensity of this line is 6 on the S. Kensington scale of 10, whereas in the nova Pickering gives the intensity as 1 on a scale of 40. The line 4121 is not present in the nova, but all the other He lines present in Bellatrix are. In Bellatrix the intensity of 4471 on the 10 scale is 8. It would appear, then, that helium is probably represented in this nova absorption spectrum, but certainly not in the same condition as in Rigel or Bellatrix.

The relation in intensity to the Mg line at 4481 is certainly not like Rigel or Bellatrix, it is more like Markab, but even there there is a marked difference. In Sirius 4471 (? helium) is <1 and 4481 is 7 (on a scale of 10), and this gives a better parallel to Pickering's relative intensities.

4481·6 (20). In the type-stars this line is due to p. Mg, but it is always a hard, sharp line. In the nova 4481·6 is the centre of a dark band (c.d.) which extends from 4474·9 to 4487·2, a breadth of 12·3 Å. In intensity it is only exceeded by the hydrogen lines. One concludes that p. Mg is probably present, but under conditions differing considerably from those obtaining in the ordinary helium stars. The other p. Mg line 4395 is not present.

4529·5 (2). An unknown line ocurring in γ Orionis (1) and in α Cygni (1) and Sirius. In the latter two it may be due to p. Ti at 4529·6.

4552·4 (2). In Bellatrix this is an intensity 3 line, probably due to p. Si (III.) 4552·8, in α Cygni (< 1), in Rigel (1). But in each of these cases the other neighbouring p. Si (III.) lines are also present, whereas in the nova they are not. Hence the silicon origin is untenable for the nova line.

4571·9 (1). In Bellatrix there is a faint unknown line (1) at λ 4570·4, which also possibly occurs as λ 4570·6 in α Cygni (< 1). In Procyon there is a line at λ 4571·2 / 4572·1 (6), probably due to Mg–p Ti, but in the nova these origins are not otherwise represented, so we cannot accept this likeness to Procyon; this also applies as regards the near line λ 4572·2 in α Pegasi.

4615·4 (1). No such line in the type-stars and no origin suggests itself.

4642·2 (2). An unknown line in Rigel at λ 4642·5 (1).

4665·0 / 4661·1 (4). No known lines of these wave-lengths in the type-stars.

4713·7 (3) / 4713·3 is the helium line found in the type stars, but its intensity in the nova spectrum, compared with the lines 4471 and 4481, is abnormal.

λλ	Intensities in				
	Nova. Max. = 40.	Rigel. = 10.	Bellatrix. = 10.	Markab. = 10.	α Cygni. = 10.
4471	1	6	8	1	1–2
4481	20	7	4	6	8
4713	3	3	4	—	—

4922·2 (2) in Bellatrix is probably due to Asterium (int. = 5) while in α Cygni there is a line (int. = 8) at 4924·1, due to p. Fe. But the other lines due to Asterium (*see* note on 4388·1) are absent from the nova, and many p. Fe lines are lacking.

A study of this table, then, leads to the conclusion that the dark-line spectrum of Nova Persei, stated by Pickering to be like Rigel, is like no spectrum we meet with in typical stars. Pickering's wave-lengths are too uncertain to permit any rigid conclusions being based on them, but, giving them the broadest interpretation possible, we can only conclude that the spectrum is not Rigelian in character.

The hydrogen lines are common to both, and it may be supposed, although there are several difficulties, that helium, asterium, and magnesium are also present. If we consider these elements, we see that the spectrum is far more like α Cygni than Rigel. The helium line 4026·4 is much too weak for it to be Rigelian or Crucian, and so are the lines at λλ 4388 and 4471. This last gives us a very striking comparison with the adjacent line, 4481 Mg.

λ	Intensities in				
	Nova. Max. = 40.	Rigelian. = 10.	Crucian. = 10.	Markabian. = 10.	Cygnian. = 10.
He. 4471 - -	1	6	8	1	1–2
Mg. 4481 - -	20	7	4	6	8

This discussion leads us to the conclusion that the evidence is certainly not in favour of the spectrum being considered as Rigelian. In fact it is almost impossible to tie it up to the spectrum of any formed star of the normal type, for whichever line we take we find several important inconsistencies.

In the second case of a nova spectrum showing dark lines only, in its first stage, Miss Cannon describes the spectrum of Nova Geminorum (2) on March 13, 1912, as "totally unlike that of any other nova so far observed, and resembled "that of the sun, except that the hydrogen lines were stronger. It appeared, "therefore, to belong to Class F5*, having also several of the dark lines "unusually well marked."†

As Miss Cannon points out, this is only the second case in which the spectrum has been photographed while the nova was increasing in brightness to its primary maximum, and in each case a strong continuous spectrum crossed by dark lines, as in a normal star, has been recorded.

As we have already shown, it is difficult to establish any detailed similarity between the dark-line spectrum of Nova Persei (2), recorded by Pickering and that of any normal star, but in the case of Nova Geminorum (2) the resemblance of the spectrum to that of Procyon is very striking. Copies of the two spectra, taken with the same dispersion and under similar conditions, are reproduced on

* Procyonian. † Harv. Coll. Obs. Circular No. 176, p. 2.

a plate accompanying the Harvard "Circular", and they present no differences that are seen at first glance. More careful examination arouses the suspicion that the spectrum is slightly stronger on the less refrangible edges of H. K., H_δ, and H_γ, in the nova spectrum than in that of Procyon, but this apparently increased intensity is not to be compared with the intensities of the bright bands that subsequently appear in these positions. There is also a slight difference of the grouping of the lines between H_δ and H_γ, the grouping in the nova spectrum being more like that in the later nova spectra (of the bright-line stage), than that in the spectrum of Procyon. Miss Cannon directs attention to this feature in saying that lines near λ 4175 are stronger in the nova spectrum, and it may be noted that there is a strong pair of enhanced iron lines $\left\{\begin{matrix} 4173 \cdot 52 \\ 4178 \cdot 95 \end{matrix}\right\}$ in this region which are conspicuous in α Cygni and come out strongly, as will be seen later, in the subsequent stage of novæ. The spectra reproduced by Prof. Pickering also show a stronger continuous spectrum in the ultra-violet in the case of the nova than in that of Procyon.

The conclusion to be drawn then, in the case of Nova Geminorum No. 2, is that a dark-line spectrum, very similar to that of Procyon, but possessing features suggestive of the later nova stage, existed during the short time that the star was rising to its primary maximum.

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3 (*c*).—A COMPARISON OF THE DARK-LINE SPECTRUM OF NOVÆ AND THE SPECTRA OF GLOBULAR CLUSTERS.

In a paper published in Vol. XXXIII. of the *Astrophysical Journal* (1911, p. 58), Dr. Fath describes some spectra of spiral nebulæ and globular clusters secured by him with the 60-inch reflector of the Mount Wilson Observatory, and tentatively suggests that his photographs afford some evidence of a progressive change in the spectra of the nebulæ with change of form. The observed changes proceed from a bright-line spectrum, through dark and bright lines to a dark-line spectrum on a strong continuous background, and, being progressive, in well-marked stages corresponding with the changes in the physical appearance of the several objects, suggest a possibility of some relation to the progressive changes in novæ spectra.

The spectra suggesting these changes are, however, on so small a scale (3 mm. from λ 3700 to λ 5000) that the greatest caution must be exercised in drawing parallels or conclusions. It may be pointed out, however, that Dr. Fath's suggested sequence from the bright-line spectrum, without continuous spectrum, found in the irregular, probably spiral forms, to an F (Procyonian) type spectrum of dark lines on a strong continuous background, found in globular clusters, is of the same kind as, although opposite in direction to, that experienced in our nova observations as shown below :—

In the Spectra of Novæ the Sequence of Changes is :—

(1) a dark-line spectrum (Procyonian*) on a strong continuous background, to
(2) a mixed spectrum of dark and bright lines, to
(3) a purely bright-line spectrum.

In the Progression from Irregular Nebulæ to Globular Clusters the Sequence of Changes is :—

(1) from a bright-line spectrum, to
(2) a mixed spectrum of bright and dark lines, to
(3) a purely dark-line spectrum of the F (Procyonian) type on a strong continuous background.

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3 (*d*).—THE "BRIGHT-LINE" SPECTRUM.

The "dark-line" condition considered in the preceding section is a very transient one, lasting but a few hours after the discovery of the nova in the two cases discussed.† It is followed by a spectrum generally much more enduring, so much so that it has become generally known as the "typical nova spectrum." This consists essentially of bright lines or bands, generally broad, and with much detailed structure, some of which are indubitably bright hydrogen bands, and are generally accompanied by absorption bands on their more refrangible ends.

One of the chief peculiarities of the spectra of novæ in this "bright-line" stage consists in the fact that in addition to the above-mentioned companion absorption bands there are other less conspicuous dark lines, or bands, which may be (1) merely the interspaces between bright lines or (2) a second set of absorption phenomena added to the above.

On the collision hypothesis, if we assume the dark lines originally observed to represent the spectrum of a dense swarm of meteorites, or a formed star, in collision, we must assume that the sparse swarm of meteorites colliding with it will not be of sufficient mass to increase largely its temperature. The greatly increased brightness is produced by the internal collisions of the swarm in question whatever its nature, and the great brilliancy will arise from these conditions and

* *Note.*—The dark-line spectrum first seen at Harvard as the spectrum of Nova Geminorum (2) was similar to that of Procyon.

† Harvard College Obs. Annals, Vol. LVI., No. 3, p. 44.
„ „ „ Circular No. 176.

not from the raising of the temperature of the denser swarm. For both these reasons it is important to consider chiefly the wave-lengths of the bright lines accompanied by dark ones, and we may disregard apparent absorption phenomena, which, from the absence of bright lines, may be referred to the effect of contrast rather than absorption.

Another fact which must be remarked is that in the spectra of those novae bright enough to have been observed in detail, the dark companions of the bright bands, *e.g.*, the hydrogen bands, have apparently been considerably displaced from their normal positions while the bright bands themselves have in general exhibited small or no displacement.

The existence of the second set of dark lines and the fact that the dark companions of the bright lines are considerably displaced has allowed two views to be held by observers engaged in measuring and reducing nova spectra. Some have measured and ascribed origins to the second set of dark lines or bands, while others have considered them merely as interspaces in a bright band spectrum.

By those observers holding the former view the dark lines have been measured, and, by allowing suitable and, at times, variable amounts of displacement, have been identified with various lines of known origin. The results so obtained strongly indicate the improbability of these dark bands being true absorption phenomena. Not only do they differ enormously from nova to nova, they differ frequently in the spectrum of the same nova taken at very brief intervals, and so suggest violent changes of physical conditions.

On the other hand, the bright bands in the spectra of novæ at this stage of their development can be recognised as identical from one nova to another. Reference to the South Kensington papers on Nova Aurigæ* and Nova Persei,† the only two novæ bright enough to be adequately observed here, will show that they are similar; further, as shown in Table V, both agree quite well with the Nova Lacertæ spectrum recorded by Wright,‡ and with the spectrum of Nova Geminorum No. 2 as reduced here from the negatives taken at Madrid.§ A brief statement of the method employed here for the reduction of the novæ spectra will illustrate the principles of this second view and why they have been adhered to at this Observatory.

* Roy. Soc. Proc., Vol. 50, pp. 408, 433, and 468.

† „ „ „ Vol. 68, pp. 122–145; Vol. 69, pp. 356–7.

‡ Lick Observatory Bulletin No. 194.

§ *See* Addendum for further observations at Mount Wilson received here after this memoir had been prepared.

3 (*e*).—PRINCIPLES EMPLOYED IN THE REDUCTION OF WAVE-LENGTHS AT SOUTH KENSINGTON.

In the reduction to wave-lengths of the lines in novæ spectra, it has been assumed that the spectrum is chiefly one of bright lines.

In the cases of Nova Aurigæ and Nova Persei comparison spectra were available. As the Madrid spectra had no laboratory comparisons it has been assumed, in order to make comparisons possible, that the bright hydrogen bands are in their normal positions, and their normal wave-lengths have been adopted in the reduction. The wave-lengths of the other bands measured, therefore, depend on the adopted normal wave-lengths of those of hydrogen, and any displacements which may be found by other observers for these bright hydrogen bands will have to be applied to the other bright bands in the spectrum, as the displacements or changes in wave-lengths may in the first instance be assumed to be common to all the bands.

Comparison of the spectra with those of various type-stars in which lines in the position of these bands have been well authenticated—such as α Cygni and Rigel—has shown that it is far easier to match the apparent *bright* bands in the novæ spectra with dark lines of normal stars, than to match the apparent *dark* lines in the novæ with dark lines in normal stars. It has, therefore, been concluded that in the majority of cases what appear to be narrow dark lines in the novæ spectra are only interspaces between the bright bands. With regard to the hydrogen radiations, however, it is certain that the bright bands are in many of the spectra accompanied by corresponding broad dark lines on the more refrangible side. Moreover, in some of the spectra these dark lines show clearly-cut bright reversals down their centres, so that the spectra cannot be considered entirely one of bright bands. Again, assuming the bright hydrogen bands to be in their normal positions, these dark hydrogen lines and the reversed lines are displaced some 15 to 20 tenth metres to the more refrangible side.

Probably in consequence of changes in wave-length produced by different streams, the strong broad bright lines are multiple and show some kind of structure. It has been thought unnecessary and entirely misleading to measure each little piece of bright and dark in the broad lines and assume that the resulting wave-length represents that of a line of some chemical element or other. Such a procedure is bound to lead to fictitious identifications. The middles of the broad hydrogen bands having been adopted for measurement, the middles of other outstanding broad bright bands have also been measured and the resulting wave-lengths adopted as representing real spectrum lines. Many of these agree so well in position with well-marked known lines in the spectrum of α Cygni, that there can be no question as to their identity. Next to hydrogen the outstanding lines in the nova spectra—in the bright-line stage—are the enhanced lines of iron.

This conclusion has been stated and reiterated in previous papers,* yet several observers, in dealing with spectra of later novæ, have published long lists of lines in which this second class of lines has been accepted as indicating real absorption, and the lines have been given origins which have differed considerably *inter se.*

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3 (*f.*)—COMPARISON OF BRIGHT LINES IN THE SPECTRA OF THE SECOND STAGE OF VARIOUS NOVÆ WITH STRONG LINES IN THE α CYGNI SPECTRUM.

In Table V. all the available spectra of the bright-line stage of novæ are brought together and are compared with the spectrum of α Cygni as photographed and reduced at South Kensington. The identity of the main features is apparent from this table, and may be recognised at a glance on Plate I., where the spectrum of Nova Geminorum No. 2 is mounted alongside the spectrum of α Cygni photographically reversed.

TABLE V.

COMPARISON OF BRIGHT LINES IN THE SPECTRA OF THE SECOND STAGE OF VARIOUS NOVÆ WITH THE STRONG ABSORPTION LINES IN THE α CYGNI SPECTRUM.

Nova Aurigæ (S. Kensington), Feb. 7 and 23, 1892.	Nova Persei (S. Kensington), Feb. 25, 1901.	Nova Lacertæ (Wright), Jan. 1910.	Nova Geminorum (2) Madrid Spectrum March 19, 1912.	α Cygni (S. Kensington).		Remarks.
				λλ	Probable Origin.	
3933	—	—	3934·6	—	—	K
3968	—	—	3969·2	—	—	H + Hε
—	—	—	4006·9	—	—	
—	—	—	4019·3	—	—	
—	—	4034	—	—	—	
—	—	—	4061	—	—	
—	4067	—	—	4067·2	p. Ni	
4101	4102	4101	4101·85	4101·8	H	Hδ
4128	4128	—	—	{ 4128·1 { 4131·1	p. Si (II) p. Si (II)	
—	—	4143	—	—	—	
4172	4175	—	4174·5	{ 4173·5 { 4179·0	p. Fe p. Fe	

* Proc. Roy. Soc., Vol. 68, p. 122; Vol. 69, p. 356.

COMPARISON OF BRIGHT LINES IN THE SPECTRA OF THE SECOND STAGE OF VARIOUS NOVÆ, &c.—*continued.*

Nova Aurigæ (S. Kensington), Feb. 7 and 23, 1892.	Nova Persei (S. Kensington), Feb. 25, 1901.	Nova Lacertæ (Wright), Jan. 1910.	Nova Geminorum (2) Madrid Spectrum, March 19, 1912.	α Cygni (S. Kensington).		Remarks.
				λ λ	Probable Origin.	
4202	—	—	—	—	—	
4226	4232	4233	4232·5	4233·3	p. Fe	
—	4247	—	—	4247·2	p. Sc	
—	—	—	4252·8	—	—	
4264	4262	—	—	4262·2	p. Cr	
—	—	—	4267·2	4267·5	p. C	Very weak in α Cygni; well seen in Bellatrix, Rigel, and other Orion stars.
4291	—	—	—	—	—	
—	4300	—	4301·1	{ 4296·7 4303·3	p. Fe p. Fe	
4310	4314	—	—	{ 4313·1 4315·1	p. Ti p. Ti	
—	—	—	4317·3	4317·2	p. Ti	
4340	4341	4346	4340·66	4340·7	H	Hγ
—	—	—	4376·4	—	—	
4383	—	—	—	—	—	
—	4392	—	4392·3	—	—	
4412	4411	4414	4408·7	4411·2	p. Ti	
—	4425	—	4423·8	—	—	
4434	4434	4434	4434·2	—	—	
—	4444	4447	—	4444·0	p. Ti	
—	—	—	4450·4	—	—	
—	4454	—	—	4455·3	p. Fe	
4469	4470	4472	4470·0	4471·6	He	
—	4481	—	—	4481·3	p. Mg	
—	4493	—	—	{ 4489·0 4491·6	{ p. Fe p. Ti p. Fe	
—	4509	—	—	4508·5	p. Fe	
4518	4519	4516	4516·4	{ 4515·5 4520·4 4522·7	p. Fe p. Fe p. Fe	
—	4535	—	—	4534·1	p. Ti	

COMPARISON OF BRIGHT LINES IN THE SPECTRA OF THE SECOND STAGE OF VARIOUS NOVÆ, &c.—*continued.*

Nova Aurigæ (S. Kensington), Feb. 7 and 23, 1892.	Nova Persei S. Kensington), Feb. 25, 1901	Nova Lacertæ (Wright), Jan. 1910.	Nova Geminorum (2) Madrid Spectrum, March 19, 1912.	α Cygni (S. Kensington). λ λ	α Cygni (S. Kensington). Probable Origin.	Remarks.
—	4548	—	4549·0	4549·8	p.Fe, p.Ti	
4555	—	—	—	—	—	
—	4568	—	—	—	—	
4587	4583	4588	4584·1	4584·0	p. Fe	
4625	4628	4625	4633·1	{ 4629·6 4635·6	p. Fe p. Fe	
—	—	—	4639	—	—	
—	—	—	4649	—	—	
—	—	—	4660·2	—	—	
—	4670	—	—	—	—	
—	—	—	4698·1	—	—	
—	4705	—	—	—	—	
—	—	—	4727·8	—	—	Well-marked unknown line in α Cygni at λ 4731.
—	4822	—	—	4824·3	p. Cr	
4860	4861	4861	4861·4	4861·49	H	Hβ*
4903	—	—	—	—	—	(Feb. 23).
—	4924	4924	No lines in Madrid Spectrum beyond Hβ	4924·1	p. Fe	
5006	—	—		—	—	
—	5019	5019		5018·6	p. Fe	
—	5169	5170		5169·2	p. Fe	
5177	—	—		—	—	
—	5224	—		—	—	
—	—	5233		—	—	
—	5273	5275		5276·2	p. Fe	
5315	5316	5318		5316·8	p. Fe	
—	5420	—		—	—	
—	5475	—		—	—	
—	5530	5535		—	—	
—	5575	5578		—	—	
5583	—	—		—	—	

COMPARISON OF BRIGHT LINES IN THE SPECTRA OF THE SECOND STAGE OF VARIOUS NOVÆ, &c.—*continued.*

Nova Aurigæ (S. Kensington), Feb. 7 and 23, 1892.	Nova Persei (S. Kensington) Feb. 25, 1901.	Nova Lacertæ (Wright), Jan. 1910.	Nova Geminorum)2) Madrid Spectrum, March 19, 1912.	α Cygni (S. Kensington.)		Remarks.
				λλ	Probable Origin.	
—	—	5664		—	—	
—	5686	5678		—	—	
—	—	5697		—	—	
570	—	—		—	—	
—	—	5754		—	—	
579	—	—		—	—	
—	5893	—		—	—	
—	—	6001		—	—	
—	—	6133–53		—	—	
—	—	6245		—	—	
630	—	6301		—	—	
—	—	6363		—	—	
656	—	6565		—	—	H_α

3 (*g*).—SPECIAL STUDY OF THE STAGE PRODUCING THE BRIGHT LINE OR BAND NEAR λ 4640, IN THE SPECTRA OF NOVÆ.

The bright band near λ 4640 has been so prominent a feature in the spectra of many novæ that it calls for special consideration. In some cases the band has, at certain epochs in the nova's history, become the brightest in the whole spectrum, and has apparently been independent of any other radiation.

In Nova Aurigæ a line at λ 4625 was recorded at South Kensington* and by Campbell† at λ 4630, but these were recorded during the α Cygni stage (February 1892), and were probably due to the enhanced iron radiation at λ 4629·5. In the later stage, however, when the nebular lines had appeared (August 1901), Campbell found a line at λ 4630 of intensity 7, where the maximum was 100.‡ This intensity was exceeded only by the lines D_3, H_β, 500,

* Roy. Soc. Proc., Vol. 50, p. 433.

† Astronomy and Astrophysics, Vol. XI., p. 807, 1892.

‡ Astronomy and Astrophysics, Vol. XII., p. 726, October 1893.

495, and 436, and ten lines of less intensity were recorded, so that the line was a fairly conspicuous feature of the spectrum. At this time the nebular lines 500 (int. = 100) and 495 (int. = 30) were exceedingly strong.

In Nova Carinæ (1895) Prof. Pickering found the bright and dark hydrogen lines on a photograph taken April 14, 1895.*

On a second photograph taken on June 15, 1895, he found the spectrum was greatly changed,—H_β, H_γ, and H_δ were still bright, but "another line, whose "wave-length is about 4700, is here as bright as the hydrogen lines. On the "photograph taken on April 14 it is barely visible." Taking into account the avowedly approximate wave-length and the small dispersion of the photograph examined, it would appear very probable that this was another record of the line under discussion.

The same line appeared in the spectrum of Nova Sagittarii (1898) photographed at the Harvard College Observatory, Arequipa, on April 19, 1898. Prof. Pickering states† that on an excellent photograph 3 mm. long the hydrogen lines $H_\beta - H_\theta$ were bright, and a bright band was seen at λ 4643. On April 21, two days later, the nebular line λ 500 appeared, although the photograph reproduced‡ shows but the faintest trace of it. Prof. Campbell§ gives the wave-length in Nova Sagittarii as 462 and the intensity as 4 on a scale where H_β is 10, λ 496 is 20, and λ 501 is 60.

Coming to Nova Persei of 1901 we find a much better spectroscopic record from many observatories, which enables us to fix the epoch of the appearance of this line with much greater certainty. A re-examination, by Mr. Rolston, of the South Kensington spectra taken with (1) the 30-inch reflector and 2-prism Hammersley spectroscope, and (2) the 9-inch prismatic reflector, shows that while on February 23, 1901, the enhanced lines of iron, &c., already referred to, were very strong, there was no certain trace of the 4639 radiation. There is a small element of uncertainty because, on the small dispersion photographs employed, the broad bright enhanced iron doublet $\left\{\begin{matrix}4629\\4635\end{matrix}\right.$ is not separable from it, but this doublet shows no sign of abnormal intensity.

Between March 10 and 21 it was impossible to secure spectrograms at South Kensington, but a very weak photograph taken on the latter date shows the 4639 line quite conspicuously, with the hydrogen lines, although the enhanced line radiations are too weak to be seen. On March 25, 26, 27, and 30 weak negatives show that, while the enhanced metallic lines had practically disappeared, the line at 4639 was very strong, being nearly equal in intensity to the hydrogen lines.

* Astrophysical Journal, Vol. II., p. 320.

† Astrophysical Journal, Vol. IX., p. 183.

‡ *Ibid.*, Plate III., p. 191.

§ *Ibid.*, p. 308.

A fairly good photograph was secured on April 4, and on this the 4639 line is both prominent and broad, being equal in intensity to H_γ, but less intense than H_β; but on April 12—the last date on which a photograph (*see* Fig. 1) was secured at South Kensington before the star's conjunction with the sun—this line at λ 4639 was the brightest and broadest in the whole spectrum, H_β, H_γ, and λ 4472 being much weaker. On this photograph the line is duplicate, having on its less refrangible side a weak radiation, of which the wave-length is not far from λ 4680.

The series of photographs at South Kensington was resumed after the conjunction, and a fairly good negative was secured with the 9-inch prismatic reflector on August 15. This shows the nebular lines fully developed, while λ 4639 is there, although very weak, and this state of things continues, so far as our photographs give any information, until the end of the series in December 1901.

Nova Geminorum (No. 1), discovered at Oxford in 1903, afforded the same phenomenon, and its spectrum appears to have reached the 4639 stage before being recorded. The star was discovered by photography on March 16, but subsequent examination of a photograph taken at the Yerkes Observatory on February 21 showed that it was then certainly fainter than the fifteenth magnitude.* A spectrum taken on March 28 shows a band at mean wave-length λ 4647 (which is recognised as the "λ 4640" of earlier novæ) as the strongest band in the spectrum. The enhanced metallic lines are not present, and Prof. Hale states† that the faint bright band in the region of the nebular band is too weak for measurement.

Later photographs taken at the Lick Observatory show that up to April 22, 1903, "λ 4625" was one of the predominant lines of the spectrum, while the nebular line 5007 was still extremely faint.‡

After conjunction with the sun, the spectrum was again observed, visually, at the Lick Observatory, and the nebular line λ 500 was found to be the strongest line in the spectrum,§ while λ 4640 was very faint or absent.

Both Nova Aquilæ (2) of 1905 and Nova Velorum of 1906 showed this radiation. On the plate (August 18, 1905) which led to the discovery of the former, the band at "λ 4646" appeared in addition to the hydrogen lines and the helium line λ 4472, and its intensity exceeded that of λ 4472. It should be noted that neither enhanced metallic lines nor the nebular lines are mentioned in Prof. Pickering's announcement,‖ but it must be borne in mind the whole spectrum was very faint. Later photographs taken at the Lick Observatory on September 6 and 10 show H_β, H_γ, and H_δ, and the same band about 100 t.m. broad, for which the mean wave-length

* Astrophysical Journal, Vol. XVII., p. 300, 1903.

† *Ibid*, p. 304.

‡ Astrophysical Journal, Vol. XVIII., page 300 and Plate XI.

§ Lick Observatory Bulletin No. 48, p. 132.

‖ Harvard College Observatory Circular 106.

is given* as λ 4600; but the spectra are very small and the measures very approximate; it is almost certainly the same radiation. The nebular lines are not shown. In the case of Nova Velorum the 4640 band accompanied the hydrogen lines H_β, H_γ, and H_δ and the nebular lines; 4472 is not given.†

Nova Lacertæ, discovered on December 30, 1910, was photographed and a spectrogram secured on January 3 with the Bruce spectrograph of the Yerkes Observatory; the spectrum showed λ 4640 as an enormously broad line, more than twice as broad, although perhaps not quite so intense, as H_β.‡

The nebular lines were not present on January 3, but later spectrograms, obtained by Mr. Parkhurst in May 1911, indicated that the λ 500 nebular line had then appeared.

Coming to the recent Nova Geminorum (2), we find that λ 4640 line again appears as a most important radiation. Bad weather prevented any series of photographs of the spectrum being obtained at South Kensington, but breaks on April 19, 22 and 23 permitted us to secure negatives with the Hammersley two-prism spectroscope attached to the 36-inch reflector. The faintness of the star and the bad state of the silvered mirror at that period prevented strong spectra being obtained, but on all three negatives the radiation at λ 4640 is the most conspicuous band, although H_β is more intense and very sharp. On April 23, λ 4640 is broad and probably double, and there is a faint impression near the position λ 4680.

Visual observations, possible through short breaks between clouds, showed that the λ 4640 band was probably developed at the commencement of April. An observation on April 11 showed the band at this position to be only second in (visual) intensity to H_β, the continuous spectrum in the neighbourhood being exceedingly weak. On April 19 the band was seen to be brighter than before relatively to H_β, and the continuous spectrum was very weak or absent. A subsequent observation on May 16 showed that the band at λ 500 was the strongest radiation, 4640 came next and then H_β.

From the above notes it will be gathered that in the changing spectra of new stars the band at "λ 4640" is probably a factor of great importance. It would appear to be a special feature of the spectrum during the interim period between the fading away of the enhanced metallic lines and the coming, or strengthening, of the gaseous nebular lines. This matter is further referred to in a subsequent section dealing with the Madrid observations of the spectrum of Nova Geminorum (2), in which the line is sometimes duplicate and the exact wave-length of the line has been determined.

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* Astrophysical Journal, Vol. XXIII., p. 262, 1906.

† Harvard College Observatory Circular No. 131.

‡ Astrophysical Journal, Vol. XXXIII., p. 410, 1906.

In the majority of cases the epoch of the band is so well-marked that we are inclined to define it as a separate phase—the "λ 4640" condition—in the evolution of novæ spectra; as such it succeeds the "enhanced metallic line" conditions and precedes the "nebular line" stage.

In many novæ in which the enhanced line condition has not been recorded, observations have been made of the presence of 4640 preceding the nebular condition.

Further, the observations suggest that since the nebular lines increase in intensity while the λ 4640 line decreases the two conditions producing these two sets of radiations are essentially different.

As in the case of the chief nebular line we have no knowledge as to the chemical origin of this band or double at λ 4640. The position of the brighter component is near that of the enhanced iron lines λλ $\begin{cases} 4629 \\ 4635 \end{cases}$, but there is no probability of its identity with this pair, for, as has been shown above, "4640" only becomes a strong band as the enhanced lines disappear from the spectrum. From the general, frequently very broad and hazy, appearance of the line in most cases we should expect the origin to be gaseous, but no known gas under known conditions gives an isolated radiation in this position. Another conclusion that appears well founded is that either the chemical nature of the origin, or the condition under which this radiation can appear, is very unstable, the whole possible existence lying sharply defined between the enhanced metallic line and the nebular condition.

This peculiar condition, like the enhanced line condition, never lasts very long. Whether the changes producing these conditions are analogous to a rise or a fall in temperature, it is important to note them, for they afford evidence of changes taking place in small masses.

The λ 4640 radiation has no counterpart among the absorption lines of normal metallic stars, nor has it been found in meteorites examined terrestrially; but, as is shown in Table VI., it has been found in several nebulæ, especially those of a planetary nature. This is to be expected, for in the nova the radiation is from a body about to assume a nebular character. The fact also points to those special nebulæ in which the radiation is found being in a different, probably a transitional, stage from those not showing it, and it may be worth while to look for evidence of change in such bodies. Apparently the λ 4640 radiation is not found in the spectrum of any ordinary irregular nebulæ, *e.g.*, that of Orion, thus differentiating them from the planetary nebulæ. Some of the light sources in which the line has been observed are set out in Table VI.

TABLE VI.

NOVÆ, NEBULÆ, &c., IN WHICH THE BRIGHT BAND AT λ 4640 HAS BEEN RECORDED.

Object.	λ given.	Date.	Remarks and Reference.
N. Aurigæ - -	4630	Aug. 1892	Int. = 7 (max. = 100). Campbell (*Astronomy and Astrophysics*, XII., p. 726, 1893).
N. Carinæ - -	About 4700	Apr. 14, 1895	As bright as the hydrogen lines. Pickering (*Astrophysical Journal*, II., p. 320).
N. Sagittarii (1) -	4643	Apr. 19, 1898	Bright band. Pickering (*Astrophysical Journal*, IX., p. 183).
" " -	462	Apr. 21, 1898	Int. 4 (where $H_\beta = 10$, λ 496 = 20, and λ 501 = 60). Campbell (*ibid.*, p. 308).
N. Persei (2) -	464	Apr. 12, 1901	Strongest line in spectrum. South Kensington.
N. Geminorum (1) -	4647	Mar. 28, 1903	Strongest line in spectrum. Hale (*Astrophysical Journal*, XVII., p. 305).
" " -	4625	Apr. 22, 1903	Predominant line. Reese and Curtis (*Astrophysical Journal*, XVIII., p. 300).
N. Aquilæ (2) - -	4646	Aug. 18, 1905	Brighter than λ 4472 ; weaker than H lines. Pickering (*H.C.O. Circular* 106).
N. Velorum - -	4640	—	*H.C.O. Circular*, 131.
N. Geminorum (2) -	4639·2	Apr. 15, 1912	Strong band, probably double. South Kensington.
P. Cygni - - -	4631	—	Frost identifies with nitrogen. (*Astrophysical Journal*, Vol. XXXV., p. 287).
Planetary nebula, N.G.C. 7,027.	463	—	Bright line ; nebular lines very bright. Campbell (*Astronomy and Astrophysics*, Vol. XIII., p. 498).
Planetary nebula in Draco, N.G.C. 6,543.	464	—	Very faint bright line ; nebular lines very bright. Campbell (*ibid.*).
Planetary nebula, G.C. 4,390.	4643	—	Faint bright line. Campbell (*ibid.*).
Planetary nebula, N.G.C. 7,662.	4645	—	Faint bright line. Campbell (*ibid.*).
Wolf-Rayet Stars generally.	4636	—	Weak, bright ; appears in 10 stars of 32 discussed by Campbell. (*Astronomy and Astrophysics*, Vol. XIII., p. 470.)
Type-Stars of Miss Cannon's Oa., Oc., Od., and Oe. classes.			
Oa.-Carinæ A.G.C. 15,305.	4633	—	Most conspicuous band, bright-line star. ζ. Puppis hydrogen lines faint. (*H.C.O. Annals*, XXVIII., Pt. 2, p. 146.)
Oc.-Scorpii, A.G.C. 22,763.	4633	—	Bright band star. ζ. Puppis hydrogen present, probably 4471 He. 4688 most conspicuous. (*H.C.O. Annals*, XXVIII., Pt. 2, p. 148.)
Od. ζ. Puppis - -	4633	—	Fairly strong, bright (with 4688) in an otherwise dark-line spectrum containing H and p. H lines. Pickering. (*H.C.O. Annals*, XXVIII., Pt. 2, p. 148).
Oe. 29 Canis Maj. -	4633	—	This line and λ 4688 the only bright lines in a spectrum of many dark lines. (*H.C.O. Annals*, XXVIII., Pt. 2, pp. 146–148.)

3 (*h*).—THE "NEBULA" SPECTRUM OF NOVÆ.

From the 4640 stage the spectra of novæ generally change gradually to one in which the ordinary "nebula" spectrum is the dominant feature. This change proceeds until the λ 500 line and other lines in the ultra-violet characteristic of nebulæ are the strongest in the spectrum.

The nebular spectrum observed in the various novæ is given in Table VII. with Wright's* general spectrum of nebulæ for comparison.

From this table it appears to be beyond doubt that in the fourth stage of the development of the spectra of new stars the radiations emitted are the same as those emitted by nebulæ in general; the minor differences are not so important as they frequently are in passing from one nebula to another.

TABLE VII.

NOVÆ SPECTRA IN THE "NEBULA" STAGE.

Nebular Lines (Wright). λλ	Novæ					Remarks.
	Aurigæ (Campbell), Aug. 1892. λλ	Persei (S. Kensington), 26 Aug. 1901. λλ	Geminorum (1) (Perrine), Apr. 1903. λλ	Lacertæ (Wright), 30 Mar. 1911. λλ	Geminorum (2) (Cambridge), 13 Aug. 1912. λλ	
—	—	342±	—	—	—	Probably the line independently recorded by Dr. von Gothard.
3726·4	—	—	—	—	—	—
3729·0	—	—	—	—	—	—
3835·8	—	—	384	—	—	H_η
3868·88	—	3868	—	—	—	—
3889·14	—	—	389	—	—	H_ζ
3965·1	396	—	—	—	—	—
3967·65	—	—	—	—	—	—
3970·23	—	3970	397	—	—	H_ϵ
4026·7	—	—	—	—	—	—
4068·8	—	—	—	—	—	—
4101·91	4098	4102	410	—	—	H_δ
—	423	—	—	—	—	—
—	426	—	—	—	—	—
4340·62	4336	4341	434	—	—	H_γ

* Astrophysical Journal, Vol. XVI., p. 53, 1902.

NOVÆ SPECTRA IN THE "NEBULA" STAGE—*continued.*

Nebular Lines (Wright). λλ	Novæ					Remarks.
	Aurigæ (Campbell), Aug. 1892. λλ	Persei (S. Kensington), 26 Aug. 1901. λλ	Geminorum (1) (Perrine), Apr. 1903. λλ	Lacertæ (Wright), 30 Mar. 1911. λλ	Geminorum (2) (Cambridge), 13 Aug. 1912. λλ	
4363·37	4358	4364	—	—	—	—
4471·71	4466	4471	446	—	—	—
—	451	—	—	—	—	—
—	460	—	—	—	—	—
—	4630	4636	4625	—	464	—
4685·73	4681	4684	—	—	—	—
—	471	—	—	—	—	—
—	—	4720	—	—	—	—
4740	—	—	—	—	—	—
—	—	4808	—	—	—	—
4861·54	4857	4862	486	4861	486	H_β.
4959·05	4953	4959	—	4959	496	2nd nebular line.
5006·89	5002	5007	—	5007	501	1st nebular line.
—	—	—	—	—	531	—
—	—	—	—	5752	575	—
—	—	—	—	6583	—	—

3 (*j*).—ON THE SPECTRUM OF NOVA GEMINORUM (2). PRELIMINARY GENERAL DESCRIPTION.

Owing to the adverse weather conditions, no successful photographs of the spectrum of Nova Geminorum (2), during its "bright-line" stage, were secured at South Kensington. By the kindness of Prof. Iniguez of the Madrid Observatory I have had placed at my disposal, for analysis and discussion, copies (positives on glass) of the admirable photographs of the spectra obtained at Madrid. The dates of these extend from March 16 to April 16 inclusive, during which period the spectrum was photographed on 26 days. With the exception of March 26, when, owing to bad weather, the photograph was not very satisfactory, all these have been copied at South Kensington by direct contact, and enlarged prints, four and a half times the originals, made from the resulting negatives. These enlargements have been placed in a sequential series and are reproduced in Plate II.

To facilitate the interpretation of the spectra, several stellar spectra in the Kensington series, such as α Cygni and ε Orionis, have been copied to the same scale as the Madrid spectra. Without going into much detail here, it may be said that a comparison with α Cygni showed at once that the chief bright lines in the earlier nova spectra agree in position with conspicuous lines in α Cygni, and there remains little doubt that the two sets of lines are identical in origin. With some modifications the chief lines in the Nova Geminorum spectra agree also with those found in previous novæ, *e.g.*, Nova Aurigæ and Nova Persei (2). From March 24 these α Cygni lines decline in intensity and other lines develop, chief of which is a strong, isolated, sometimes double, line at λ 4639, seen most conspicuously in the spectra of April 6 and 15.

The earlier photographs show another customary feature of novæ spectra in that the bright hydrogen lines are accompanied on the more refrangible side by well-marked dark lines. These vary in structure from day to day. On some days they are beautifully divided centrally by a sharp radiation line or reversal. In other cases the dividing line is broader and the two dark component parts of the whole absorption line are very unequal in intensity.

These variations are emphasised in the three successive photographs of March 24, 25 and 27.

Taking H_γ as an example, on the first date the absorption line is divided by a comparatively narrow bright line and the two portions of the dark line are fairly equal in intensity, the more refrangible being slightly the stronger. On the next day the dividing bright line is a little broader and the difference in intensity between the two dark components is accentuated. On March 27 the dividing bright line is still broader and the stronger dark component is now on the less refrangible side.

There is distinct evidence, also, in the photographs of March 24 and 25, that not only are the hydrogen lines accompanied by dark lines, but the bright line in the position of the helium line 4471 and the bright enhanced iron lines at λλ 4176, 4233 have similar accompanying broad dark lines, these also being divided by a narrow bright line, but not in such a decisive manner as in the case of some of the hydrogen lines.

The detailed reduction and discussion of these spectra, carried out by Mr. Baxandall, is given below. In Table VIII. appear the wave-lengths and probable origins of the bright bands seen on the negative of March 19 when the enhanced lines of α Cygni were predominant.

TABLE VIII.

MADRID SPECTRUM, MARCH 19.

* = Fiducial lines used for reduction to wave-lengths.

λ	Probable Origin.	λ of Probable Origin.	Remarks.
3934·6	Ca	3933·83	Middle of K (Ca).
3960·2			Violet edge of H_ϵ.
3969·2	H	3968·63	Middle of broad H_ϵ (+ H Ca).
3976·3	Ca	3970·25	Middle of strong maximum in H_ϵ.
3979·2			Red edge of H_ϵ.
4006·9	—	—	Weak narrow radiation.
4019·3	—	—	,, ,, ,,
4061·0	—	—	Middle of broad weak line with ill-defined edges.
4081·5	H	—	? Reversal in dark $H\delta$.
4090·7			Violet edge of $H\delta$.
*4101·85	H	4101·85	Middle of $H\delta$.
4109·6			Middle of strong maximum in $H\delta$.
4112·3			Red edge of $H\delta$.
4154·4	—	—	Detached narrow bit of radiation.
4161·3			Violet edge of broad line.
4174·5	p. Fe	4173·61, 4179·05 } 4176·35	Middle of strong broad line.
4182·0			Red edge of strong broad line.
4188·0			
4222·1			Violet edge of broad bright line.
4232·5	p. Fe	4233·32	Middle of broad bright line.
4242·9			Red edge of broad bright line.
4252·8	—	—	Weak narrow radiation.
4267·2	—	—	,, ,, ,,
4291·3			Violet edge of broad bright line.
4301·1	p. Fe	4296·72, 4303·34 } 4300·03	Middle of broad bright line.
4311·1			Red edge of broad bright line.
4317·3	—	—	Detached narrow radiation on violet side of $H\gamma$, probably reversal in dark $H\gamma$.
4328·5			Violet edge of $H\gamma$.
*4340·66	H	4340·66	Middle of $H\gamma$ line.
4353·3			Red edge of $H\gamma$.
4357·9	—	—	Narrow radiation bordering $H\gamma$. Probably the less refrangible portion of a broad line, part of which is hidden by bright $H\gamma$, this broad line being probably identical with the α Cygni—proto-iron line 4351·9.
4376·4	—	—	Narrow strong radiation.
4392·3	—	—	,, ,, ,,
4408·7	—	—	Narrow and rather weak radiation.
4423·8	—	—	Narrow and fairly strong radiation.

MADRID SPECTRUM, MARCH 19—*continued.*

λ	Probable Origin.	λ of Probable Origin.	Remarks.
4434·2	—	—	Detached narrow bit of radiation.
4450·4	—	—	" " " "
4456·4 4470·0 4483·3	He	4471·65	Violet edge of weak broad bright line. Middle of weak broad bright line. Red edge of weak broad bright line.
4496·8 4498·5 4514·7 4516·4 4532·8	p. Fe	4508·46 4515·51 4520·40 4522·77 Mean 4516·78	Extreme violet edge of broad line. Detached bit of radiation in broad line. Position of maximum intensity in broad line. Middle of broad line. Red edge of broad line.
4537·4 4549·0 4560·2	p. Fe	4549·64	Violet edge of broad line. Middle of broad line. Red edge of broad line.
4572·7 4584·1 4594·9	p. Fe	4584·02	Violet edge of broad line. Middle of broad line. Red edge of broad line.
4623·4 4633·1 4643·9	p. Fe	4629·51 4635·50 4632·50	Violet edge of broad line. Middle of broad line. Red edge of broad line.
4660·2	—	—	Middle of broad line, the violet edge of which merges into 4633 line.
4674·7	—	—	Diffuse red edge of broad line.
4698·1	—	—	Weak radiation.
4727·8	—	—	" "
4848·1 *4861·49 4875·0	H	4861·49	Violet edge of Hβ. Middle of Hβ line. Red edge of Hβ.

For the type of spectrum where the enhanced lines have nearly disappeared and of which the chief feature is the broad and apparently double line near λ 4640, the spectrum of April 7 has been measured. The results are given in the following Table IX. The width of the whole band at λ 4640, taken in its dual aspect, is about 70 tenth-metres.

TABLE IX.

MADRID SPECTRUM, APRIL 7.

* = Fiducial lines used for reduction to wave-lengths.

λ	Probable Origin.	λ of Probable Origin.	Remarks.
3889·1	H	3889·1	Middle of H_ζ line.
3970·2	H	3970·25	Middle of H_ϵ line.
*4101·85	H	4101·85	Middle of bright H_δ line.
4174·5	p. Fe	4173·61 4179·05 4176·33	Middle of weak broad line.

MADRID SPECTRUM, APRIL 7—*continued.*

λ	Probable Origin.	λ of Probable Origin.	Remarks.
4232·5	p. Fe	4233·32	Middle of weak broad line.
4263·5	—	—	—
4301·1	p. Fe	{ 4296·72, 4303·34 } 4300·03	Middle of weak broad line.
4330·0	H	4340·66	Violet edge of bright H_γ.
*4340·66			Middle of bright H_γ.
4351·0			Red edge of bright H_γ.
4470·3	He	4471·65	Middle of weak broad line.
4516·4	p. Fe	{ 4508·46, 4515·51, 4520·40, 4522·77 } Mean 4516·75	Middle of rather weak broad line.
4549·0	p. Fe	4549·64	Middle of weak broad line.
4584·1	p. Fe	4584·02	Middle of rather weak broad line.
4602·4	—	—	Weak violet edge of broad bright band.
4628·6			Middle of brightest portion of broad bright band.
4644·7			Middle of dividing dark line in compound broad bright band.
4659·6			Middle of weak less refrangible portion of broad bright band.
4672·2			Red edge of broad bright band.
*4861·49	H	4861·49	Middle of bright H_β.

For the type of spectrum which shows the line near λ 4639 as strong and isolated, the photograph of April 15th has been selected for measurement. The details are given in Table X. The position of the line near 4639 was independently measured by three observers, and the wave-length given is the mean of the three measures.

TABLE X.

MADRID SPECTRUM, APRIL 15.

* = Fiducial lines used for reduction to wave-lengths.

λ	Probable Origin.	λ of Probable Origin.	Remarks.
3970·25	H	3970·25	Middle of bright H_ϵ.
*4101·85	H	4101·85	Middle of bright H_δ.
*4340·66	H	4340·66	Middle of bright H_γ.
4470·2	He	4471·65	Middle of weak broad line.
4639·2	—	—	Middle of strong isolated bright line.
4680·2	—	—	Middle of weak broad line.
*4861·49	H	4861·49	Middle of bright H_β.

NOTE.—In addition to the lines in the above list there are three weak lines between H_ϵ and H_δ; three between H_δ and H_γ and five between H_γ and H_β. These are so weak, however, as to be almost lost when the magnification of the measuring machine is used on them. Those between H_δ and H_γ are probably the lines λλ 4176, 4233, and 4264.

DETAILED DISCUSSION OF THE SPECTRUM OF NOVA GEMINORUM (2), MARCH 16—APRIL 16, 1912.

In addition to the main features of the spectrum of Nova Geminorum (2), already discussed in the preliminary general statement, and shown in Tables VIII., IX., and X., there were many less conspicuous but important details shown in the plates; also very striking changes took place throughout the spectrum from time to time, such as were recorded for the spectra of the earlier novæ. These details and changes are dealt with by Mr. Baxandall in the discussion that follows, the spectrum for each day being treated separately. *See* Plate II.

March 16.—The bright hydrogen lines H_β H_γ H_δ H_ϵ are shown, H_γ being the strongest. Lines H_β, H_γ, and H_δ appear to have a fine reversal down the centre. This is best seen in the H_γ line. On the more refrangible side of H_γ is a well-defined absorption line, the width of which is about one-third that of the bright H_γ line. There is also a suspicion of absorption lines to the left of H_β and H_δ, but these are not so definite as that at H_γ. The K line of calcium and probably the H line (superposed on H_ϵ) are seen as rather faint broad radiations. Between H_γ and H_δ the usual nova bands at λλ 4176, 4233, 4300 are seen, but not conspicuously. These are to be ascribed to the enhanced lines of iron at λλ $\left\{\begin{matrix}4173\cdot61\\4179\cdot05\end{matrix}\right.$ 4233·32 and $\left\{\begin{matrix}4296\cdot72\\4003\cdot34\end{matrix}\right.$ which are so well shown in α Cygni. Between the last of these and the dark H_γ, and fringing the latter, there is another narrow radiation, which, however, may be a portion of the complex structure of the whole H_γ radiation.

Assuming the apparent middle of the H_γ absorption line to be the real middle, which may easily be a false assumption, this is displaced from the fine dark line in the middle of the broad bright H_γ an amount equivalent to 15·3 tenth-metres, which, if the displacement is assumed to be due to a velocity effect (another assumption which may be proved false by future research), shows a relative velocity of rather more than 1,000 kms. per second for the two bodies producing the dark and bright hydrogen lines.

From H_γ to about λ 4650 there is a complex series of faint and rather broad radiations with apparent fine absorption lines amongst them. Judging from the development of these broad lines or bands in the nova spectra of subsequent dates it is fairly certain that most of the faint bright bands in the spectrum of March 16 can be ascribed to enhanced lines of iron which occur prominently in α Cygni. Without committing oneself definitely to the assertion that the apparent dark lines are only, in general, interspaces between broad bright bands, it appears likely that such is the case.

March 17.—The hydrogen lines H_β H_γ H_δ H_ϵ (superposed on H calcium) and the K line of calcium have developed considerably in intensity, the first three showing rather complex structure. There are two, possibly three, distinct maxima of brightness, the least refrangible being the brightest. The difficulty of deciding whether the most refrangible of the three maxima in H_γ and H_δ is really part of the hydrogen radiation rests in the fact that the Madrid spectra are taken with an objective prism and there is no laboratory comparison spectrum to enable us to say which are really the middles of the complex hydrogen lines. The H_ϵ and K radiations are rather diffuse and show little structure. The enhanced-iron radiations at λλ 4176, 4233, 4300 have strengthened from the previous day, and the same remark applies to the complex series of bands between H_γ and λ 4650. The identification of most of these individual lines with laboratory lines is made very difficult owing to a succession of probably overlapping images, but the fact that in other parts of the nova spectra where the enhanced lines of iron are more isolated (between H_γ and H_δ and on the less refrangible side of H_β) all these special lines of the element named agree in position with well-marked nova lines, taken together with the fact that there are about seventeen enhanced iron lines in the region H_γ to 4650, where the nova spectrum is so complex, would appear to make it almost certain that the enhanced lines of iron are the chief factor in the nova spectrum. Another significant fact is that in the region λ 4650 to H_β, where no enhanced lines of iron occur, the nova spectrum is almost a complete blank.

On the less refrangible side of H_ϵ in the spectrum of March 17th there is what appears to be a broad absorption line, but whether this is a genuine absorption line or only an interspace between the bright H_γ line and the next bright line on the less refrangible side of H_γ is doubtful.

The structure of the 4300 line (probably a double in itself) combined with the complex structure of the neighbouring H_γ line gives the appearance of a set of six fairly sharp emission lines with dark interspaces or absorption lines between. As, however, it is fairly evident that the nova spectrum consists chiefly of broad bright lines showing considerable structure in themselves, it seems almost useless to measure the position of each bit of radiation and each bit of apparent absorption, and use the resulting wave-length as a means of possibly identifying these bits with lines of chemical elements. Such a method is almost certain to give fictitious and misleading identifications. In dealing with novæ spectra it must be borne in mind that the number of radiation lines is probably small, and that the type of line is broad and one showing some structure.

In the region of H_γ to λ 4650 the probably overlapping images of the individual lines makes it difficult, if not impossible, to tell which are the real middles of the lines. A similar difficulty presents itself in deciding whether the narrow dark portions of the spectrum in this region are real absorption lines or interspaces between bright lines or bands. Judging from their narrowness, as compared with the width of the well-authenticated bright lines, the latter is more likely to be the real interpretation.

March 18.—There is not much difference between the spectrum of this date and that of the 17th. The structure of the hydrogen lines shows the less refrangible portion of the bright lines distinctly stronger than the remaining portion. The extra radiation to the left of H_γ and H_δ, which on the 17th gave the appearance of a possible third maximum in the radiations, is entirely missing. H and K are about as on the 17th. The three bands λλ 4176, 4233, 4300 are the only ones well visible between H_δ and H_γ. The dark hydrogen lines to the violet side of the bright ones are present but not conspicuous.

March 19.—The hydrogen lines are now very strong, H_β and H_γ being divided in the middle by an apparent absorption line. The two bright components in the structure of these lines are now nearly equal in intensity. The bright H_δ line does not show the same structure as the others. It is distinctly brighter at the red edge and then keeps fairly uniform in intensity up to the violet edge, giving the appearance of a winged line rather than a double as at H_γ and H_β. The H_ϵ line is of a dual nature, the less refrangible component being much stronger and better defined than the more refrangible. The K line is also double, but the difference in intensity of the two components is not nearly so well marked as in H_ϵ which probably involves the H calcium line.

The broad lines λλ 4176, 4233, 4300, are now quite conspicuous and have more definite edges than in previous photographs. They also show somewhat similar structure to the hydrogen lines H_γ and H_β. The lines between H_γ and λ 4650 show better definition. Several of these now show the same structure as the three lines between H_γ and H_δ; being broad lines with fairly well developed edges and divided down their width by fine dark lines. There can be little doubt that the enhanced lines of iron at λλ $\begin{Bmatrix} 4508 \cdot 46 \\ 4515 \cdot 51 \\ 4520 \cdot 40 \\ 4522 \cdot 77 \end{Bmatrix}$, $\begin{Bmatrix} 4549 \cdot 64 \\ 4556 \cdot 09 \end{Bmatrix}$, 4584·02 and $\begin{Bmatrix} 4629 \cdot 51 \\ 4635 \cdot 50 \end{Bmatrix}$, all well represented in α Cygni, are involved in the four bright bands in this region. Which these lines are will be gathered from reference to Plates I. and II. Owing, probably to the varied bunching of these sets of lines, the structure in the different nova lines is not quite the same. The apparent absorption lines between the members of this set of bright broad lines have probably no significance as spectrum *lines*, being only interspaces. The lines H_β H_γ and H_δ are accompanied by narrow dark lines—not very conspicuous, especially in the reproduction in Plate II.

March 20.—Very similar to spectrum of March 19, except that there is not so much detail shown in the individual lines. The brighter portion of the H_ϵ line is not so accentuated here as on the 19th. Two or three weak diffuse lines have developed in the region between 4650 and H_β, which region was in previous spectra almost void of radiation lines. The enhanced iron line 4924·1, conspicuous in α Cygni and kindred stars, is fairly well shown. Lines H_β, H_γ, and H_δ are still bordered by rather broad absorption lines, but of no great density. At H_γ and H_δ these absorption lines are divided in the middle by a weak radiation. If the H_β absorption line is similarly divided it is not very evident.

March 22.—Of the spectra up to and including this date, that of March 22 shows most detail in the spectrum lines. The most conspicuous feature is undoubtedly the very black absorption lines which accompany the bright hydrogen lines, especially H_β, H_γ, and H_δ. These are about three-quarters the width of the corresponding bright lines, and H_γ and H_δ are beautifully divided in the centre by sharp radiation lines or reversals. There is a suspicion that dark H_β is similarly divided. The bright hydrogen lines are still not uniform in intensity throughout their width, there being two maxima of brightness fairly equally divided by a portion of considerably less intensity. Between H_β and H_γ the outstanding lines are still those at λλ 4176, 4233, and 4300, which show somewhat similar structure to the hydrogen lines and are about the same width. Line λ 4300, however, seems more split up than the other two, and shows two maxima of intensity more conspicuously than they do. The intensity curve of this line is not symmetrical. On the violet side of lines λλ 4176 and 4233 there are broad absorption lines similar to the dark hydrogen lines, but not nearly so dense. These absorption lines also show similar structure to the dark hydrogen lines, being divided down their centres, but not so definitely as in the hydrogen lines. A few minor radiations have here developed in addition to the three main bands.

The spectrum between H_γ and H_β still shows a complex system of radiation lines or bands of varying width, but in most cases they can be called broad lines. Between these are what appear to be narrow absorption lines, but the probability is that these are only gaps between bright lines, and their estimated wave-lengths probably have no significance. At any rate, if these are assumed to be genuine lines, to be consistent one should estimate the positions of each portion of the dark hydrogen lines, and adopt these as wave-lengths of absorption lines. It is scarcely necessary to point out that such a procedure would give wave-length numbers of no value in so far as identifying the lines of chemical elements is concerned. From the wave-length values obtained from the middles of the broad radiation lines it is fairly evident that many of these agree with strong lines in the spectrum of α Cygni, which in the majority of cases have been shown to be identical with enhanced lines of iron. On the less refrangible side of H_β the enhanced iron lines λλ 4924·11 and 5018·63 (very conspicuous in α Cygni) are easily seen in the spectrum of this date.

March 23.—The spectrum of this date is practically a replica of that of the 22nd; the only striking difference is that the radiation band, the middle of which agrees with the position of the λ 4471 line of helium, is now somewhat narrower. and the absorption line or interspace on the violet side of it correspondingly broader than on the 22nd.

March 24.—Very similar to the spectra of the 22nd and 23rd. The only notable differences from the spectrum of the 23rd are:—

(1) The absorption lines bordering the bright hydrogen lines are denser, and thus show more contrast from the bright lines.

(2) The absorption lines on the violet side of the nova bands at λλ 4176 and 4233 are more conspicuous and show, more distinctly than heretofore, the same structure as the dark hydrogen lines, viz., they are divided down the centre by a radiation line or reversal.

(3) The absorption line to the left of the bright line at λ 4471 shows more definite structure than previously. It is divided centrally by a fairly fine bright line, but the less refrangible portion of the absorption line taken as a whole is far blacker and more conspicuous than the more refrangible portion.

(4) The broad radiation band, the middle of which is at λ 4549, shows a little more structure, as it is now crossed by an apparently thin absorption line at about one-third of its width inside the less refrangible edge.

All the lines referred to in the spectrum of this date will easily be recognised by reference to Plates I. and II.

March 25.—The spectrum shows some very striking changes from those of the three previous days, which were much alike. There appears to be far more continuous spectrum than in any of the earlier spectra, and the radiation lines or bands, although they are identical in position with those in the other spectra, do not stand out prominently. The most striking change, however, is in the dark hydrogen lines. In the spectra of March 22, 23, and 24 they were very conspicuous, broad, and dense lines, with fine bright dividing lines down the centres.

On the 25th the dividing line is considerably wider and more noticeable, and the more refrangible portions of the dark hydrogen line is in each case stronger than the portion bordering the broad bright hydrogen lines. In fact, what is probably only a portion of the width of the whole absorption line of hydrogen stands out quite prominently as an apparent narrow and sharp absorption line. The bright hydrogen lines have a very sharp edge on the violet side, but are very diffuse on the red side, giving the appearance almost of a fluting. The structure in the bright lines is not very apparent.

March 27.—The bright hydrogen lines are still very conspicuous. The dark hydrogen lines have again changed considerably. The most refrangible part which stood out so prominently on March 25 is now very weak, the less refrangible portion bordering the strong bright hydrogen lines being the more conspicuous. The bright hydrogen lines now show a broad and intense portion very sharply cut on the more refrangible side, less so on the less refrangible side, with some structure shown in the middle. There is another part of the hydrogen radiation—not very broad and far less intense than the main portion—on the red side of the latter and giving rather the appearance, on the whole, of a strong bright line winged on the red side. There is in the Madrid positive a weak absorption line dividing the very bright portion of the hydrogen line from the less bright portion, but this is not so evident in the reproduction.

The bands at λλ 4176, 4233, and 4300 are present but faint. In the spectrum between H_γ and H_β striking changes have taken place from the 25th. From H_γ to about λ 4500 most of the lines seen in previous spectra have now practically disappeared, leaving as the only outstanding feature between H_γ and H^β the three bands at λλ 4515, 4549, and 4584, all present in previous spectra, and a much stronger broad band (probably a double broad line), whose mean position is about λ 4640 and width about 60 tenth-metres. The broad band is probably not a development of the pair of broad lines occupying an approximately similar position in the earlier spectra, but an extra line due to some substance or other, which has come into existence with the changed conditions in the nova. The three other lines mentioned above are probably the remnants of enhanced lines of iron which occur so prominently in the earlier spectra.

March 28.—Not very much different from March 27. The hydrogen lines, taken as a whole, show a complex structure. There is a broad bright portion divided in the middle by a rather indistinct dark reversal or absorption line. Then on each side of the bright line there is a rather narrow absorption line, the one on the violet side being far more conspicuous than the other. Then again on the outside of each of these absorption lines there are portions of radiation, but of considerably less intensity than that of the main radiation.

The whole appearance of the hydrogen lines gives the impression of there being a broad intense bright line showing a black reversal, this bright line being nearly centrally superposed on a broad dark line, which again is centrally superposed on a broad bright line of less intensity than the central portion.

The other lines remain about the same as on March 27.

March 29.—Thin photograph. No striking change from March 28.

April 1.—Very little different from March 28 and 29. There has appeared a rather broad, indistinct radiation in the position of the λ 4471·6 line of helium, but as there does not seem to be a corresponding radiation at λ 4026·3, the position of another helium line nearly always associated in stellar spectra with λ 4471·6, the helium origin cannot be unreservedly accepted. The structure of the complex hydrogen lines shows some slight modifications from March 28, but as this change seems more developed in the photographs of April 2 and 3, fuller discussion is reserved for the spectra of these dates.

Apart from the hydrogen lines, the most outstanding line is still the broad one whose mean position is λ 4639, and which seems to be of a dual nature, with the stronger and broader component on the more refrangible side.

April 2.—The hydrogen lines H_β and H_γ exhibit complex structure. The main portion is a double bright line, the less refrangible component being the brighter. The dark dividing line is very narrow in H_β, less so in H_γ. On either side of the strong bright H^γ line there is an absorption portion, that on the violet side being the broader. On the outside, again, of each of these bits of absorption is a narrow bit of radiation, and yet again outside these pieces of radiation there are narrow bits of absorption. All the separate pieces mentioned are probably parts of a very complex structure in the hydrogen lines.

The H_δ line shows somewhat different structure from that in H_γ. The definite dual nature of the very bright radiation at H_γ is not seen in H_δ. The least refrangible portion of the broad bright line is distinctly strongest, but the rest, up to the more refrangible edge, is of fairly uniform intensity, but split up by two rather indistinct narrow lines. The brightest, least refrangible portion of the bright line is fringed on the red side by a portion of radiation of less intensity, with a bit of absorption between the two. On the violet side of the broad bright line there is a piece of absorption, then another bit of radiation, then again a narrow piece of absorption, which in the reproduction is lost in what appears to be a broad uniform absorption line. Here again all the separate pieces of apparent radiation and absorption are probably part of a very complex structure of the H_δ line.

The bands at $\lambda\lambda$ 4176, 4233, 4471, 4515, 4549, 4584 are present, but not very strong. The broad and diffuse line at λ 4639 is still seen. The K line of calcium is very weak.

April 3.—Very similar to April 2. The structure of the hydrogen lines is still very complex; H_δ differing considerably from H_γ and H_β. The absorption lines to the left of H_β and H_γ, taken in their broad aspect, are divided by a bright line, not in the nature of a fine narrow reversal, the width of the bright dividing line being about the same as each of the two portions of absorption which the line divides. At H_δ, however, this broad absorption line is not equally divided by a radiation line, the more refrangible part of the absorption being a little broader than the right-hand portion and the bright dividing line combined. There seems to be a recrudescence of some of the lines which appeared on the red side of H_γ in some of the earlier photographs. Most of the enhanced iron lines are still seen in the nova spectrum. The spectrum in its main features is not unlike that of March 19, except that the enhanced iron lines are weaker in the later spectrum and there is considerable difference in the lines between H_γ and λ 4515. The broad hazy band at λ 4640 which has been in the spectrum since March 27 is here better defined, not so broad, and more centrally divided and very similar to that of March 19. The H_ϵ line is a broad double, the less refrangible component being much the stronger. The K line is very weak and this is one of the most striking differences between the spectrum of this date and that of March 19.

April 4.—Not a very good photograph. The most notable change is that the prominent line at λ 4640 has again assumed a broader and more diffuse appearance and, although double, is not symmetrically divided, the more refrangible portion being far the stronger.

April 5.—Similar in its general features to the spectra of April 3 and 4. The broad diffuse line near λ 4640 now shows no indication of being a double line as it was on April 3 with a clear dividing line down the centre. The enhanced lines and λ 4471 are still seen, but not prominently.

April 6.—The line near λ 4640 is here a far more compact line than heretofore and it is very nearly as prominent as the hydrogen lines. It shows no suggestion of duality and it is easier to get a fairly accurate measure of its position than in previous photographs. Using the hydrogen lines as fiducial lines its wave-length has been calculated to be about λ 4639. An extra radiation —not very strong—has now appeared about λ 468, but whether this is a trace of the chief line λ 4686 in the series of hydrogen lines discovered by Prof. Pickering in ζ Puppis is doubtful. The radiation at λ 4471 and the enhanced iron radiations at λλ 4176, 4233, 4515, 4549, 4584, are still shown weakly. An extra radiation at about λ 4264 is here fairly well seen for the first time, though there was a trace of it in the spectra of April 4 and 5.

April 7.—The bright hydrogen lines now show the less refrangible portion much brighter and there is a dividing line of absorption, but not very distinct. The most striking change from the spectrum of April 6 is in the region near λ 4640. The comparatively sharp and compact bright line of April 6 (λ 4639) is replaced by a broad diffuse double as in the spectra of April 2 and 4. The more refrangible component of this double is much the stronger. The peculiar point is that the line of the 6th fits neither of the components of the double of the 7th. Neither does it seem to coincide with either the dividing line of the bright double nor with the middle of this double taken as a whole, although it approximates more closely to the latter position than to any one of the other three. The remnants of some of the enhanced iron lines (λλ 4176, 4233, 4515, 4549, 4584) are still faintly seen. Also the radiations near λλ 4264 and 4471.

April 8.—Not a very good spectrum. From what can be seen in it, however, there is no decided change from April 7. The lines in general are a little narrower than in the preceding photograph, but this may be accounted for by lack of exposure.

April 9.—Very similar to that of April 8, the line near λ 4640 being a little narrower.

April 10.—Very similar to April 8 and 9, except that the line near λ 4640 has further narrowed.

April 13.—A weak photograph. Only the hydrogen lines H_β, H_γ, H_δ and H_ϵ seen, with a trace of the line near λ 4640.

April 15.—The spectrum is now almost a replica of that of April 6, in which the line λ 4639 had assumed such a compact and comparatively well-defined appearance. The bright hydrogen lines show a similar structure to that of April 6. Also faint traces of λλ 4233 (p. Fe), 4264, 4471, 4515 (p. Fe), 4584 (p. Fe), and 4680.

April 16.—The spectrum has again greatly changed in the vicinity of λ 4640 from that of the previous night, again showing the broad diffuse bright double line of April 7. This is the only very significant change, but there also appears to be a change in the relative intensities of some of the minor bands between λ 4471 and λ 4650.

4.—RELATION OF THE NOVA SPECTRA TO THE BRIGHT-LINE SPECTRA OF OTHER STARS.

(*a*) WOLF-RAYET STARS.

The spectra of a number of stars display bright lines mixed, in various ways, with dark lines which are frequently of known origin, and this has suggested to many observers the probability that some direct relations may be established between such stars and novæ.

The most numerous class of bright-line stars is that discovered by M.M. Wolf and Rayet, and studied at some length by Campbell, who has given a list of lines* observed by him photographically and visually.

In Table XI. we give in the first column all the lines recorded by Campbell in 31 Wolf-Rayet stars, and in the second column the number of stars in which each line was observed; the signs + and ++ preceding certain λλ in the first column indicate "bright" and "very bright," respectively. The data given in columns 3, 4, 7, 8 and 9 are also taken from Campbell's paper. The discussion of the origins embodied in the column for "Remarks" has been undertaken by Mr. Baxandall.

Other celestial light sources are included in Table XI., so that no suggested relation may escape notice; the various headings to the several columns are sufficiently explanatory.

* Astronomy and Astrophysics, Vol. XIII., p. 448.

TABLE XI.

Wolf-Rayet Stars.		Solar Chromo-sphere.	Nova Aurigæ (Lick).	Nova Persei (Kensing-ton).	Nova Gemi-norum (Madrid).	Gaseous Nebulæ.	Orion Stars (Dark Lines).	β Lyræ (Dark Lines).	Remarks.
λλ	No. of Stars observed in.								
+4023	1	—	—	—	—	4026	4026	4026	Almost certainly due to helium 4026·3.
—	—	—	—	—	4061·0	—	—	—	
+4063	3	—	4067	4067	—	4067	4067	4062	In novæ and gaseous nebulæ, of unknown origin. The 4067 line of Campbell in Orion stars is probably the diffuse line occurring in Alnitamian stars near the most refrangible line of the oxygen triplet 4070, 4072, 4076. This has had no satisfactory origin assigned to it.
++4102	4	4102Hδ	4102	4102	4101·85	4102	4102	4102	H_δ.
—	—	—	—	4128	—	—	—	—	Probably the equivalent of the silicium double { 4128·20. 4131·04.
—	—	—	—	—	4154·4	—	—	—	
—	—	—	—	4175	4174·5	—	—	—	Probably the equivalent of the proto-iron double { 4173·61. 4179·05.
420	4	—	—	—	—	—	4203	—	Almost certainly the proto-hydrogen line of ζ Puppis, &c.
4228	3	—	4228	4232	4232·5	423	423	—	In novæ almost certainly due to proto-iron 4233·32. Origin in gaseous nebulæ unknown. Certainly not proto-iron in that spectrum. The 423 line in Orion stars given by Campbell is almost certainly proto-iron, but only occurs in the lowest group (Rigelian) of those comprising the Orion stars.
—	—	—	—	4247	—	—	—	—	
—	—	—	—	—	4252·8	—	—	—	
4260	2	—	4262	4262	—	—	—	—	Doubtfully due to proto-chromium (4262): stronger proto-chromium lines apparently not represented.
—	—	—	—	—	4267·2	—	—	—	Possibly p. C 4267·4.
4273	4	—	—	—	—	—	—	—	
—	—	—	—	4300	4301·1	—	—	—	Probably the equivalent of the proto-iron double { 4296·72. 4303·34.

4318	5	—	4316	4314	4317·3	—	—	—	Doubtfully due to proto-titanium (4315) in novæ. There is an oxygen line at 4318, but in the absence of the characteristic oxygen lines in Wolf-Rayet stars and gaseous nebulæ the radiation there is probably due to something other than oxygen.
4334	1	—	—	—	—	—	—	—	
+ +4341	9	4341 Hγ	4341	4341	4340·66	4341	4341	4341	Hγ.
4369	4	—	—	—	—	—	—	—	In the absence of the most characteristic lines of oxygen, this cannot be ascribed to 4367 oxygen.
—	—	—	—	—	4376·4	—	—	—	
+4389	2	—	—	4392	4392·3	4389	4389	4388	Doubtfully due to Asterium 4388·1. Other stronger asterium lines are missing (notably 4922).
—	—	—	—	—	4408·7	—	—	—	
—	—	—	—	4411	—	—	—	—	Possibly p. Ti 4411·20.
4416	1	—	4418	—	—	—	4416	—	In novæ almost certainly due to proto-iron 4417·0. In Orion stars to oxygen {4415, 4417} in the absence of the most characteristic lines of proto-iron and oxygen in bright-line stars, this line in Wolf-Rayet stars cannot well be ascribed to either p. Fe or O.
—	—	—	—	4425	—	—	—	—	
—	—	—	—	4434	4434·2	—	—	—	
+ +4443	10	4444	4445	4444	—	—	—	—	In the chromosphere undoubtedly due to proto-titanium 4444·0. Possibly also in novæ. No satisfactory evidence for Fe origin as given by Campbell. This very strong line in Wolf-Rayet stars is certainly not identical with the p. Ti chromospheric line 4444·0.
—	—	—	—	—	4450·4	—	—	—	
4457	1	—	—	4454	—	—	—	—	
+4466	4	—	—	—	—	—	—	—	
+4473	2	4472	4473	4470	4470·0	4472	4472	4471	Very probably helium 4471·6.
4480	5	4481 Mg	4481	4481	—	—	4481	4481	Very probably due to p. Mg 4481·4.
4493	2	4490 Fe	4490	4493	—	—	—	—	Probably due to proto-iron {4489·35, 4491·57} in chromosphere and novæ. Cannot be ascribed to proto-iron in Wolf-Rayet stars, as many more prominent p. Fe lines are missing.

TABLE XI.—*continued.*

Wolf-Rayet Stars. λλ	Wolf-Rayet Stars. No. of Stars observed in.	Solar Chromo-sphere.	Nova Aurigæ (Lick).	Nova Persei (Kensing-ton).	Nova Gemi-norum (Madrid).	Gaseous Nebulæ.	Orion Stars (Dark Lines).	β Lyræ (Dark Lines).	Remarks.
+4504		—	—	—	—	—	—	—	
4509	8	—	4507	4509	—	—	—	4510	In novæ possibly the origin is proto-iron 4508·5. In the absence of other proto-iron lines in Wolf-Rayet stars, the Wolf-Rayet line can scarcely be ascribed to proto-iron.
—		—	—	—	4514·7	—	—	—	
+4517		—	—	4519	4516·4	—	—	—	Probably p. Fe 4515·5.
—	—	—	—	4535	—	—	—	—	
+ +4541	19	—	—	—	—	—	454	4544	Probably proto-hydrogen line of ζ Puppis.
—	—	—	—	4548	4549·0	—	—	—	Proto-iron λ 4549·64.
4555	1	4556 Fe	4556	—	—	—	—	4556	In chromosphere and novæ, probably due to proto-iron 4556·06. No evidence for p. Fe in Wolf-Rayet Stars.
—	—	—	—	4568	—	—	—	—	
—	—	—	—	4583	4584·1	—	—	—	Proto-iron λ 4584·02.
4596	5	—	—	—	—	—	—	—	
4615	6	—	—	—	—	—	—	—	
4626	5	4630 Fe	4629	4628	—	—	—	4630	In chromosphere and novæ, probably due to proto-iron 4629·51. In β Lyræ due to nitrogen 4630·7. In the absence, however, of the characteristic lines of proto-iron and nitrogen from bright-line-star spectra this line at 4626 probably has some other origin.
—	—	—	—	—	4633·1	—	—	—	Probably the equivalent of the proto-iron double { 4629·51. 4635·50.
+4636	10	—	—	—	—	—	—	—	

+ +4652	16	—	—	—	—	—	4652	4652	This line in Orion stars is of varying origin. In Bellatrix the chief origin is probably O $\left\{ \begin{array}{l} 4649\cdot2 \\ 4651\cdot0 \end{array} \right.$ In the Alnitamian stars the chief source is proto-carbon $\left\{ \begin{array}{l} 4647\cdot6 \\ 4650.8 \end{array} \right.$ Comparison of Mr. McClean's Orion star spectra with γ Argus shows that the very strong line in the latter is not identical with the Orion star line, being less refrangible. So that at present this will have to be classed as an "unknown" line in Wolf-Rayet stars.
—	—	—	—	—	4660·2	—	—	—	
—	—	—	—	4670	—	—	—	—	
+ +4688	31	—	—	—	—	4687	4688	—	Probably the ζ Puppis line of proto-hydrogen.
—	—	—	—	—	4698·1	—	—	—	
—	—	—	—	4705	—	—	—	—	
—	—	—	—	—	4737·8	—	—	—	
4787	14	—	—	—	—	—	—	—	
—	—	—	—	4822	—	—	—	—	
+ +4862	22	4861Hβ	4862	4862	4861·4	4861	4861	4861	Hβ.
—	—	—	—	4924	—	—	—	—	
4940	15	—	—	—	—	—	—	—	
5020	14	5019 Fe	5016	5019	—	—	5021	(5014)	In chromosphere and novæ chiefly (if not wholly) due to proto-iron 5018·6. In Orion stars generally due to asterium 5015·73. As the two asterium lines 4922 and 5015 are always associated and the former is apparently lacking in Wolf-Rayet stars, the 5020 line cannot with confidence be ascribed to asterium.
5131	13	—	—	—	—	—	—	—	
—	—	—	—	5169	—	—	—	—	Probably p. Fe 5169.
—	—	—	—	5224	—	—	—	—	
5250	6	—	—	—	—	—	—	—	
—	—	—	—	5273	—	—	—	—	

TABLE XI.—*continued.*

Wolf-Rayet Stars. λλ	Wolf-Rayet Stars. No. of Stars observed in.	Solar Chromosphere.	Nova Aurigæ (Lick.)	Nova Persei (Kensington).	Nova Geminorum (Madrid).	Gaseous Nebulæ.	Orion Stars (Dark Lines).	β Lyræ (Dark Lines).	Remarks.
5284	3	5285 Fe	5285	—	—	—	—	—	No satisfactory evidence for origin being Fe as suggested by Campbell.
—	—	—	—	5316	—	—	—	—	Probably p. Fe 5316·79.
++5412	24	—	—	—	—	5412	—	—	Probably proto-hydrogen line of ζ Puppis.
—	—	—	—	5420	—	—	—	—	
+5472	13	—	—	5475	—	—	—	—	
—	—	—	—	5530	—	—	—	—	
—	—	—	—	5575	—	—	—	—	
+5593	15	—	—	—	—	—	—	—	
—	—	—	—	5686	—	—	—	—	
++5693	18	—	—	—	—	—	—	—	
++5813	21	—	—	—	—	—	—	—	
5848	1	—	—	—	—	—	—	—	
+5877	9	5876 D_3	—	—	—	5876	5876	5876	D_3.
—	—	—	—	5893	—	—	—	—	? D.
6564	5	6563 Hα	6563	—	—	6562	—	—	Hα.

From this table and the accompanying remarks it is obvious that the spectra of Wolf-Rayet stars and novæ in the bright-line stage have very little in common beyond the hydrogen lines. But the Wolf-Rayet stars are essentially gaseous masses from which the metals, in the form producing the enhanced lines of the nova bright-line stage, have been eliminated, so far as radiation is concerned, and therefore we must naturally look for similarity to the Wolf-Rayet spectra in the spectra of novæ in the λ 4640 and nebular stages, where we find gaseous bright lines only and none due to metals. Under such conditions temperature alone probably plays a less, and electrical effects a greater, part in the production and variation of radiation.

In Table XII. we give a comparison of Campbell's Wolf-Rayet spectra with the spectra of novæ in these later stages.

Column 1 contains the Wolf-Rayet lines published by Campbell,* with a frequency number showing in how many stars of the 31 studied by him each line occurs. Column 2 contains Campbell's results† for Nova Aurigæ when in the nebular stage, and 3 the spectrum of Nova Persei as photographed and reduced at South Kensington.‡

The wave-lengths given in column 4 for Nova Geminorum (1) comprise two sets, one published by Perrine§ and the other by Messrs. Reese and Curtis‖; the latter are given to four figures. In column 5 are given the wave-lengths of the spectrum of Nova Lacertæ published by Dr. Wright¶ and derived from photographs taken, at the Lick Observatory, when the nebular line λ 5007 was the strongest line in the spectrum. All the preceding columns deal with the nebular stage only, the λ 4640 stage not having been treated separately in previous novæ. But in the sixth and seventh columns we give two sets of wave-lengths, the first showing those of the few bright bands in the Madrid spectrum of Nova Geminorum (2) when in the λ 4640 stage (*see* p. 32), measured at South Kensington, and the second those of the same nova when in the nebular stage as recorded by Stratton**; in the latter the numbers in brackets show the order of intensity of the bands.

* Astronomy and Astrophysics, Vol. XIII, p. 468.

† *Ibid*, Vol. XII., p. 726.

‡ Proc. Roy. Soc. Vol. 69, p. 135, 1901.

§ Astrophysical Journal, Vol. XVIII., p. 297.

‖ *Ibid.*, pp. 299–306.

¶ Lick Observatory Bulletin No. 194, p. 100.

** Monthly Notices, Vol. LXXIII., p. 72.

TABLE XII.

COMPARISON OF THE SPECTRA OF WOLF-RAYET STARS AND OF NOVÆ IN THE NEBULAR STAGE.

1		2		3		4		5	6	7	
Wolf-Rayet Stars (Campbell).	Frequency of Occurrence. Max. = 31.	Nova Aurigæ (Campbell), August 1892.		Nova Persei (South Kensington), August 26, 1901.		Nova Geminorum (Perrine) and (Reese and Curtis), April 1903.		Nova Lacertæ (Wright), March 30, 1911.	Nova Geminorum (2). (South Kensington) 4640 Stage, April 15, 1912.	(Stratton), Nebular Stage. Dec. 6, 1912.	Origin.
λλ		λλ	Int. Max. = 10.	λλ	Int. Max. = 10.	λλ	Int.	λλ	λλ	λλ	
—	—	—	—	—	—	384	—	—	—	—	H_η
—	—	—	—	3868	10	—	—	—	—	—	Hδ
—	—	—	—	—	—	389	—	—	—	—	—
—	—	396	tr.	3970	8	397	—	—	3970·2	—	H_ϵ
—	—	—	—	—	—	3982	—	—	—	—	—
4023	1	—	—	—	—	—	—	—	—	—	He
4063	3	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	4090	—	—	—	—	—
4102	4	4098	0·2	—	—	410	—	—	4101·8	H_δ (7)	H_δ
420	4	—	—	—	—	—	—	—	—	—	—
4228	3	423	0·1	—	—	—	—	—	—	—	—
4260	2	426	0·1	—	—	—	—	—	—	—	—
4273	4	—	—	—	—	—	—	—	—	—	—
4318	5	—	—	—	—	—	—	—	—	—	—
4334	1	—	—	—	—	—	—	—	—	—	—
4341	9	4336	0·1	4341	2	434 4342	v.s.	—	4340·6	H_γ (5)	H_γ
4369	4	4358	0·8	4364	7	—	—	—	—	436 (1)	—
—	—	—	—	—	—	4378	—	—	—	—	—
4389	2	438	0·1	—	—	—	—	—	—	—	Ast.
4416	1	—	—	—	—	—	—	—	—	—	—
4443	10	—	—	—	—	—	—	—	—	—	—
4457	1	—	—	—	—	—	—	—	—	—	—
4466	4	—	—	—	—	—	—	—	—	—	—
4473	2	4466	0·1	4471	1	446	—	—	4470·2	—	He
4480	5	—	—	—	—	—	—	—	—	—	p. M_g

COMPARISON OF THE SPECTRA OF WOLF-RAYET STARS AND OF NOVÆ IN THE NEBULAR STAGE—*continued*.

1		2		3		4		5	6	7	
Wolf-Rayet Stars (Campbell).	Frequency of Occurrence. Max. = 31.	Nova Aurigæ (Campbell), August 1892.		Nova Persei (South Kensington), August 26, 1901.		Nova Geminorum (Perrine) and (Reese and Curtis), April 1903.		Nova Lacertæ (Wright). March 30, 1911.	Nova Geminorum (2). (South Kensington) 4640 Stage, April 15, 1912.	Nova Geminorum (2). (Stratton), Nebular Stage, Dec. 6, 1912.	Origin.
λλ		λλ	Int. Max. = 10.	λλ	Int. Max. = 10.	λλ	Int.	λλ	λλ	λλ	
4493	2	—	—	—	—	—	—	—	—	—	—
4504 } 4517 }	8	451	0·1	—	—	—	—	—	—	—	—
—	—	—	—	—	—	4536	—	—	—	—	—
4541	19	—	—	—	—	—	—	—	—	—	p. H
4555	1	—	—	—	—	—	—	—	—	—	—
4596	5	460	0·1	—	—	—	—	—	—	—	—
4615	6	—	—	—	—	—	—	—	—	—	—
4626	5	—	—	—	—	462	—	—	—	—	—
4636	10	4630	0·7	4636	3	4630	—	—	4639·2	464 (3)	Unk.
4652	16	—	—	—	—	4656	—	—	—	—	—
4688	31	4681	0·4	4684	2	—	—	—	4680·2	468 (8)	p. H
—	—	471	0·1	4720	6	—	—	—	—	471 (9)	—
4787	14	—	—	—	—	—	—	—	—	—	—
—	—	—	—	4802	<1	—	—	—	—	—	—
4862	22	4857	1	4862	3	486 4861	s.n.	4861	4861·49	H_β (4)	H_β
4940	15	—	—	—	—	—	—	—	—	—	—
—	—	4953	3	4959	2	—	—	4959	—	496 (6)	2nd neb.
—	—	5002	10	5007	4	5007	—	5006	—	501 (2)	1st neb.
5020	14	—	—	—	—	—	—	—	—	—	—
5131	13	—	—	—	—	—	—	—	—	—	—
5250	6	—	—	—	—	—	—	—	—	—	—
5284	3	—	—	—	—	—	—	—	—	—	—
5412	24	—	—	—	—	—	—	—	—	—	p. H
5472	13	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	5557	—	—	—	—	—
5593	15	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	5671	—	—	—	—	—

COMPARISON OF THE SPECTRA OF WOLF-RAYET STARS AND OF NOVÆ IN THE NEBULAR STAGE—*continued.*

1		2		3		4		5	6	7	
Wolf-Rayet Stars (Campbell).	Frequency of Occurrence. Max. = 31.	Nova Aurigæ (Campbell), August 1892.		Nova Persei (South Kensington), August 26 1901.		Nova Geminorum (Perrine) and (Reese and Curtis). April 1903.		Nova Lacertæ (Wright). March 30, 1911.	Nova Geminorum (2). (South Kensington) 4640 Stage, April 15, 1912.	Nova Geminorum (2). (Stratton), Nebular Stage. Dec. 6, 1912.	Origin.
λλ		λλ	Int. Max. = 10.	λλ	Int. Max. = 10.	λλ	Int.	λλ	λλ	λλ	
5693	18	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	5739	—	—	—	—	—
—	—	5750	—	—	—	—	—	5752	—	—	—
5813	21	—	—	—	—	—	—	—	—	—	—
5848	1	—	—	—	—	—	—	—	—	—	—
5877	9	—	—	—	—	—	—	—	—	—	D_3
6564	5	—	—	—	—	—	—	6563	—	—	H_α

As most of these wave-lengths in Table XII. are connected with the nebular stage we deal with that first, leaving the precedent λ 4640 stage till later.

At first sight the table conveys the impression that although there are more points in common between the Wolf-Rayet stars and novæ in the "nebula" stage, than between the former and the enhanced-line stage of novæ, the agreement is not conclusive.

The hydrogen lines are common, but apart from them there is no known element certainly represented in both types of spectra. The helium line λ4471 appears in most of the novæ, but it is not accompanied by the other helium lines, such as λ 4026, the next line of the same series, and, so far as has been recorded by Campbell, only appears as a bright line in two of the thirty-one Wolf-Rayet spectra, although it was photographed as a dark line in three others. On the other hand the visual observations revealed the presence of D_3 in nine stars of the Wolf-Rayet type, and in all there is evidence, more or less complete, for the presence of helium in 12 of the 31 stars observed by Campbell; but only in three stars is helium represented by more than one line, and in one of these the second line (λ 4471) is dark while the other (D_3) is bright. We cannot, therefore, definitely claim helium as a common connecting element between novæ and Wolf-Rayet stars.

As regards proto-hydrogen, Rydberg's principal series, as represented by the λ 4688 line, appears in every Wolf-Rayet spectrum examined by Campbell, and is possibly represented in the "nebula" spectrum of Novæ Aurigæ, Persei (2), and Geminorum (2); the other lines of this series, recently photographed terrestrially by Fowler,* are too far in the ultra-violet to be shown in photographs of stellar spectra. The absence of the other p. H lines, the ζ Puppis series, is not conclusive evidence against the p. H origin in the novæ, for the two lines λ 4542 and λ 4201

* Monthly Notices, Vol. LXXIII., No. 2, December 1912.

are only represented nine and four times, respectively, in the Wolf-Rayet spectra, and the λ 4688 line, as Rydberg has pointed out,* is much the strongest line of all the hydrogen series and might, therefore, be expected to reveal itself when the other p. H were too weak to show; the ordinary hydrogen lines are considerably weakened when the novæ spectra reach the nebular stage.

From this evidence we conclude that the connection between the spectra of novæ in the nebular stage and those of Wolf-Rayet stars in general is almost entirely dependent upon the identity of the ordinary and the Rydberg principal series of hydrogen.

But if we consider specific Wolf-Rayet spectra in connection with the λ 4640 stage of novæ, we find a stronger resemblance between the two classes of stars. Before doing this it should be remarked that Campbell's list of lines given in Table XII. is a summation of a large number (31) of the star spectra in which the individuals differ considerably *inter se*, and that many stars of the Wolf-Rayet type could not be observed at Mount Hamilton.

The specific Wolf-Rayet spectra that are similar to the spectrum of the novæ in the λ 4640 stage are to be found among those of Miss Cannon's O class (Argonian) stars. Thus in the spectrum of the typical star (— Carinæ A.G.C. 15305) of the Oa class, a star too far south for Campbell to deal with, Miss Cannon finds † that "a broad bright band, whose centre is at the wave-length 4633 is the " most conspicuous feature of this spectrum. On the side of shorter wave-length " the edge of this band is well defined and resembles a dark line; on the side " of greater wave-length, the brightness fades off into a fainter band of nearly equal " width, which may coincide with band 4688 seen in classes Ob, Oc, Od, and " Oe." The general spectrum consists of bright bands on a faint continuous background, no dark bands being present. In addition to the two already named the only other bands in the spectrum are H_δ, H_γ, and possibly the λ 4471 helium line; the ζ Puppis series of hydrogen lines may be there, but are not seen with certainty on any photograph.

A comparison between this spectrum described by Miss Cannon and the spectrum of Nova Geminorum (2) in the λ 4640 stage (given in Table X.) is made in Table XIII. on the following page.

In making this comparison it must be recognised that very few lines are involved and any conclusions drawn from it may therefore appear somewhat doubtful. But on the other hand the few lines are an outstanding characteristic of both spectra, remarked by Miss Cannon in the case of the Oa type-star and obvious in the case of the nova [Geminorum (2)] on reference to Table X.

It is also important to note that in the Oa spectrum the bright bands appear on "a faint continuous background," and reference to the Madrid spectra (Plate II.) shows that when (April 15) the 4640 stage is arrived at, the continuous spectrum has almost disappeared. Visual observations on April 11 and 19 (*see* p. 24) also revealed the faintness of the continuous spectrum.

* Astrophysical Journal, Vol. VI., p. 237.

† "Spectra of Bright Southern Stars," H.C.O. Annals, Vol. XXVIII., Part II., p. 146.

TABLE XIII.

Nova Geminorum (2), λ 4640 Stage, April 15, 1912. South Kensington.			Typical Oa Star (— Carinæ, A.G.C. 15305). Harvard.		
λλ	Orig.	Remarks.	λλ	Orig.	Remarks.
3970·25 (3 weak lines.)	H	Middle of bright H_ϵ	4059		
4101·85 (3 weak lines.)	H	Middle of bright H_δ	4101·8	H	
4340·66	H	Middle of bright H_γ	4340·7	H	
4470·2	He	Middle of broad weak bright band.	4471·8	He	
4639·2	—	Middle of strong isolated bright line.	4633	—	Broad bright band, most conspicuous feature in spectrum; fades off into fainter band which may coincide with 4688.
4680·2	? p. H	Middle of weak broad line, diffuse to measure, possibly 4688 of Rydberg's H series.	4688		
4861·49	H	Middle of bright H_β			
			Also the ζ Puppis hydrogen lines are suspected as bright, but are not clearly seen on any photograph.		

Thus we find a general similarity between the spectra of the λ 4640 stage of novæ and the Oa (Wolf-Rayet) spectra, a similarity which extends to practically all the features exhibited by these spectra.

Prof. Fowler has shown that to get the p. hydrogen lines showing clearly in laboratory spectra, electrical discharges of great intensity are necessary* in the vacuum tube. In the novæ spectra the special conditions are clearly not fully attained, but the presence of the λ 4688 radiation in both novæ and the Oa spectra, and the possible presence of the bright ζ Puppis series in the latter, indicates the probability that in the atmosphere of these stars the laboratory conditions are approached.

With regard to the apparent variation of the wave-length for the "λ 4640" radiation as given by different observers in different stars, it must be borne in mind that the line is always broad and sometimes diffuse and therefore difficult to measure. Further, many of the measures have been made visually or on photographs of very small dispersion and they must therefore be held to be liable to large probable errors. In the type-stars, Miss Cannon gives the value as 4633, in γ Velorum (Oa Pec.) the mean wave-length is given as 4635·7, while Copeland's visual measures at Vincocaya† gave 464·6 and our recent measures of the band in Nova Geminorum (2) gave 4639·2. It is, however, probable that the same radiation was measured in each case.

* Monthly Notices, R.A.S., Vol. LXXIII., No. 2, December 1912.

† Copernicus, Vol. III., p. 205.

In relation to novæ, which show simultaneously bright and dark lines in their spectra, it is interesting to note the features which differentiate the spectra of the several groups of Pickering's O class. This class has, in the Kensington classification, been treated as a whole and is designated "Argonian," but in the Harvard classification it is subdivided into five groups, Oa to Oe inclusive; a similar subdivision of the "Alnitamian" class has recently been made at South Kensington.*

In the Oa class, as we have seeen, the radiation λ 4633 is the strongest and occurs in a spectrum of bright lines only, the continuous spectrum being weak; λ 4688 and, possibly, the ζ Puppis hydrogen lines are also present. In the Ob class the λ 4633 band is absent, λ 4688 is very intense and the ζ Puppis hydrogen lines are present; again the spectrum is purely a bright-line spectrum. In Oc λ 4688 is still the most conspicuous feature, but λ 4633 is present with the additional hydrogen lines, and no dark lines are shown. Class Od (ζ Puppis) shows all dark lines except λ 4688 and λ 4633, but the spectrum contains only four lines in addition to the two series of hydrogen. On the other hand, the Oe class contains many dark lines in addition to λλ 4633 and 4688, which are bright. By an intermediate stage (the Oe_5B class) the Harvard classification passes to the purely dark-line stage represented by ϵ Orionis (B, or Alnitamian, type) in which λλ 4633 and 4688 are not represented and the ζ Puppis lines are fainter. Thus, we see that in the Argonian stars, as in novæ, the λ 4633 bright line comes out as a prominent feature approximately at that stage where bright lines are associated, in some form or another, with dark lines; this, also, suggests a similarity between novæ in the "λ 4640" stage and Wolf-Rayet stars.

There is another suggested relation between Wolf-Rayet stars and novæ which should not be overlooked. Prof. Hartmann found, on examining a photograph of the spectrum of Nova Persei, taken on October 15 and 18, 1907, that "*das novaspektren fast vollkommen identisch mit dem spektrum des Wolf-Rayet-Sterns BD* 35° 4001."†

This, coming after the nebular stage, at first suggested the possibility of a reversion in the spectral changes of the nova. The star BD 35° 4001 is of a fairly typical Wolf-Rayet character,‡ its spectrum, according to Campbell, including the radiations λλ 4862, 4650, 4627 (+), 4598, 4541 (+), 4508, 4481, 4465, 4442, 4369, 4341 (+), 420 (+), 4102 (+), and 406. In both the nova and the Wolf-Rayet spectra the line 4687 was the strongest, but the small scale of the photographs used by Prof. Hartmann made it impossible to go into any detail.

In answer to an inquiry Prof. Hartmann very kindly informed me that the two spectra displayed a general similarity in the distribution of radiation, the

* On the Spectra of the Rigelian, Crucian and Alnitamian Stars. Solar Physics Committee Publications, 1914.

† Astronomische Nachrichten, No. 4232, col. 115, Vol. 177.

‡ Astronomy and Astrophysics, Vol. XIII., p. 462.

maxima occurring as stated in his original note. but further than that he was unable to go owing to the faintness and small scale of his spectra. Thus, while it is obvious that between the winter of 1901 and that of 1907 some marked change occurred in the spectrum of Nova Persei, we have not sufficient data to enable us to fix definitely a stage in the spectrum, or a physical condition, which would bring the nova at that epoch into line with the other phenomena attendant upon novæ.

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4 (*b*).—OTHER BRIGHT-LINE STARS AND NOVÆ.

In addition to the Wolf-Rayet stars, there are a number of stars giving bright radiations in their spectra. In some cases absorption lines accompany the radiation lines, in others the dark lines are sporadic, while in other examples, *e.g.*, β Lyræ, the relative positions of the dark and bright companions change about from time to time.

These stars are not very numerous among the brighter objects, and their spectral phenomena—beyond the existence of bright lines—vary so greatly from star to star that it is almost impossible to classify the objects in more detail. But although the phenomena are so varied and the objects relatively few, the problems presented are probably among the most important in astrophysics.

In the following table (XIV.), we bring together the bright lines recorded in the spectra of several such objects, and compare them with the spectra of Nova Geminorum (2) in the "bright-line" and the "λ 4640" stages, and the spectrum of Nova Persei (2) in the nebular stage. It is necessary to take two novæ into consideration, because in the case of Nova Persei the λ 4640 stage was not considered specifically, while in the case of Nova Geminorum (2) we have not yet a complete analysis of the nebular stage.

TABLE XIV.

BRIGHT LINES IN THE SPECTRA OF NOVÆ IN DIFFERENT STAGES, AND OF BRIGHT-LINE STARS.

N. Geminorum (2), Madrid Spectra, South Kensington reduction.		N. Persei (2) (South Kensington)	P. Cygni (Frost).	μ Centauri (South Kensington).	β Lyræ (Pickering and South Kensington.)	Remarks.
"Bright-line" stage, Mar. 19, 1912. λλ	"λ 4640" stage, Apr. 15, 1912. λλ	Nebular stage, Aug. 26, 1901. λλ	λλ	λλ	λλ	
—	—	342±	—	—	—	von Gothard's nebular line.
—	—	—	—	—	3819·2	
—	—	—	—	—	3856·2	
—	—	3868	—	—	—	
—	—	—	3889	—	3887	H_ζ + He.
3934·6	—	—	3933	—	—	p. Ca.
—	—	—	3964	—	—	He.
3969·2	3970·25	3970	3970	—	—	H_ϵ + H (Ca).
—	—	—	3995	—	—	N.
4006·9	—	—	—	—	—	

BRIGHT LINES IN THE SPECTRA OF NOVÆ IN DIFFERENT STAGES, AND OF BRIGHT-LINE STARS—*continued.*

N. Geminorum (2), Madrid Spectra, South Kensington reduction.		N. Persei (2) (South Kensington),	P. Cygni (Frost)	μ Centauri (South Kensington)	β Lyræ (Pickering and South Kensington).	Remarks.
"Bright line" stage, Mar. 19, 1912. λλ	"λ 4640" stage, Apr. 15, 1912. λλ	Nebular stage, Aug. 26, 1901. λλ	λλ	λλ	λλ	
4019·3	—	—	—	—	—	
—	—	—	4026	—	4026·4	He.
4061·0	—	—	—	—	—	
4081·5	—	—	—	—	—	Apparent reversal in dark H_δ.
4101·85	4101·85	4102	4102	4101·8	4101·8	H_δ.
—	—	--	4121	—	4120·5	He.
—	—	—	4143	—	4144·0	He.
4154·4	—	—	—	—	—	
4174·5	—	—	—	4176·4	—	p. Fe.
4232·5	—	—	—	4232·9	—	p. Fe.
4252·8	—	—	—	—	—	
4267·2	—	—	—	—	—	? p. C.
4301·1	—	—	—	4299·4	—	p. Fe.
4317·3	—	—	—	—	—	
4340·66	4340·66	4341	4340	4340·6	4340·6	H_γ.
—	—	—	4349	—	—	O.
—	—	—	4351	—	—	O.
4357·9	—	—	—	—	—	Narrow radiation bordering H_γ. Probably the less refrangible portion of a broad line, part of which is hidden by bright H_γ, this broad line being probably identical with the α Cygni p.Fe line λ 4351·9.
—	—	4364	—	—	—	
—	—	—	4367	—	—	O.
4376·4	—	—	—	—	—	
—	—	—	—	4385	—	p. Fe.
—	—	—	4388	—	4387·8	He.
4392·3	—	—	—	—	—	
4408·7	—	—	—	—	—	
—	—	—	4419	—	—	
4423·8	—	—	—	—	—	
4434·2	—	—	—	—	—	
4450·4	—	—	—	—	—	
4470·0	4470·2	4471	4472	—	4471·8	He.
—	—	—	—	4508·9	—	p. Fe.
4516·4	—	—	—	4515·1	—	p. Fe.
—	—	—	—	4523·3	—	
4549	—	—	—	4549·9	—	p. Fe.
—	—	—	—	4556·3	—	
4584·1	—	—	—	4584·6	—	p. Fe.
—	—	—	4491	—	—	O.
—	—	—	4601	—	—	N.
—	—	—	4607	—	—	N.
—	—	—	4622	—	—	N.
—	—	—	4631	—	—	N.
4633·1	—	—	—	—	—	p. Fe.
—	4639·2	4636	—	—	—	
—	—	—	4643	—	—	N.
4660·2	—	—	4661	—	—	O.
—	—	—	4676	—	—	O.
—	4680·2	—	—	—	—	

BRIGHT LINES IN THE SPECTRA OF NOVÆ IN DIFFERENT STAGES, AND OF BRIGHT-LINE STARS—*continued.*

N. Geminorum (2), Madrid Spectra, South Kensington reduction.		N. Persei (2) (South Kensington.)	P. Cygni (Frost).	μ Centauri (South Kensington)	β Lyræ (Pickering and South Kensington.)	Remarks.
"Bright line" stage. Mar. 19, 1912 λλ	"λ 4640" stage, Apr. 15, 1912. λλ	Nebular stage, Aug. 26, 1901. λλ	λλ	λλ	λλ	
—	—	4684	—	—	—	
4698·1	—	—	—	—	—	
—	—	—	4713	—	4712·8	He.
—	—	4720	—	—	—	
4727·8	—	—	—	—	—	
—	—	4808	—	—	—	
4861·49	4861·49	4862	4861	4861	4861	H_β.
—	—	—	4923	—	4923·7	He.
—	—	4959	—	—	—	
—	—	5007	—	—	—	
—	—	—	5016	—	5023	He.
—	—	—	5055	—	—	
—	—	—	5127	—	—	
—	—	—	5155	—	—	
—	—	—	5240	—	—	
—	—	—	5876	—	—	He (D_3).
—	—	—	6563	—	—	H_α.
—	—	—	6678	—	—	He.

This comparison does not show any striking likeness between any of these typical bright-line stars and novæ. The hydrogen lines are common to all, and so is the λ 4471 helium line, excepting μ Centauri, but many other helium lines which appear in P Cygni and β Lyræ are absent from all the novæ spectra here dealt with. The spectrum of μ Centauri does resemble that of the novæ in the bright-line stage, in that many of the lines are due to proto-iron, but they are not always the same lines. No analogue of the nova λ 4640 stage presents itself, and the entire absence of the typical nebular lines from the bright-line spectra considered, absolutely debars any analogy being drawn between these spectra and the nebular-stage spectrum of the novæ.

Thus, we arrive at the conclusion that the physical conditions obtaining in novæ, in any of the stages pictured in their spectra, are very dissimilar to those obtaining in the typical bright-line stars considered in the above table.

5.—THE STRUCTURE OF THE BANDS IN NOVÆ SPECTRA.

One of the most striking features of the spectra of novæ, especially when in the "bright-line" stage, is the multiple character of the broad bright bands, particularly those of hydrogen, such as might be expected if we were dealing with a complicated system in which the different units were moving in the line of sight with enormously different velocities.

In most novæ spectra this phenomenon has been remarked, and in the case of Nova Aurigæ the strange and apparently varying multiplicity was so puzzling that Schumann pointed out* that if a multiple system were invoked to explain it, the system would have to be at least sextuple. Belopolsky's results, quoted by Vogel,† required an even greater complexity to explain them.

In the case of Nova Persei (2), many intensity curves of various lines, principally of hydrogen, were published. The South Kensington intensity curves appeared in several papers communicated to the Royal Society in 1901,‡ and showed numerous changes in the dispositions and intensities of the maxima seen in the hydrogen lines. If these varying displacements be taken as a Doppler-Fizeau effect, the relative velocities shown by the extreme bright maxima of H_β amounted to as much as 1,000 miles per second, while the relative velocity of the two central maxima was about 200 miles per second. It is to be noted that these broad, bright bands generally do not fade in intensity from one edge to another, but usually have sharply defined edges on both sides, indicating that the motions, if motion can be held accountable for the shifts, are those of well-defined streams of matter, each stream moving with its own peculiar velocity.

In the case of H_γ the early photographs showed three maxima, the two outside ones being broad, the middle one narrow, although almost of equal intensity; the curve resembles the sharp double reversal such as is found in the solar calcium lines H and K in the neighbourhood of a solar disturbance. Between February 25 and March 10, 1901, the maximum intensity in this band changed from the more to the less refrangible side of the bright band.

In the case of Nova Geminorum No. 2 this complicated structure of the bright bands, in the bright-line stage, was again a pronounced feature, and the oscillations of the maxima within the bands was remarked by many observers. The changes exhibited on the Madrid spectrograms are discussed in Section 3 (*j*), and it should be noted that the phenomena were shared by the bright metallic bands, similar structure appearing on the same date and all varying together from one date to another, thus showing the complex chemical nature of the matter which produced the radiations.

As the spectra of novæ change from the "bright-line" stage to the later stages, the complicated structure tends to disappear with the subsidence of the disturbance until, in the "nebula" stage, the bands are much more homogeneous. In addition to the complex bright lines in the "bright-line" stage, there are also the dark companions to the hydrogen lines to be considered. These do not show the same structure as do the bright lines, but do suffer changes in apparent positions and appearance. At times they are not separated from the bright bands, and the suggestion has been made that their less refrangible

* Astronomy and Astro-Physics, Vol. XII., p. 159. † *Ibid.*, Vol. XIII., p. 56.

‡ Roy. Soc. Proc., Vol. 68, pp. 143, 144, 233, 234 and 404.

edges might be masked by the emission, thus making it impossible to determine the wave-lengths of the centres of the dark bands; but at other epochs there has been a distinct space between the less refrangible edge of the dark, and the more refrangible edge of the bright, bands. Examples of this are shown on Plate II., where the division between the bright and dark components may be seen on the photographs of March 25–April 5.

6.—MAGNITUDE OBSERVATIONS OF NOVÆ.

The phenomena attending novæ in their early stages are so obviously cataclysmic in character that one would *a priori* expect strongly-marked oscillations in the general light-emission. Such oscillations have been observed in the magnitudes of those novæ which have been discovered immediately after their first appearance during the early stages of their spectral changes.

The light-curve of Nova Aurigæ was a very remarkable one. Less bright than the eighth magnitude on December 8, 1891, it was of about magnitude 5·0 when discovered by Dr. Anderson on February 1, 1892, and then, after reaching a maximum, it declined gradually, with many intervening brightenings on a small scale,* until on April 26, 1892, it had sunk so low as the sixteenth magnitude,† according to Prof. Burnham's observations with the 36-inch refractor at the Lick Observatory. But observations made at the same observatory on August 17, 1892, showed that the nova had brightened considerably, and was then of magnitude 10·5, while two days later it had become 9·8, where it remained steady for a long period.

Coming to Nova Persei (2), observations, made at South Kensington from February 25 to May 5, 1901, were plotted on a curve,‡ and showed that the magnitude was an oscillating quantity. From this and from the much more extensive data collated by Prof. Pickering§ it is seen that while the increase of light to the primary maximum took the form of an enormous uprush, unbroken by any fluctuation, the decrease was relatively much more gradual and was marked by very frequent oscillations.

In a communication to the Royal Society in June 1901‖, I pointed out that the spectrum of the nova appeared to vary in sympathy with the changes in magnitude, and this was confirmed by several other observers.

Prof. Pickering showed that during the period March 17–April 28, 1901, the spectrum varied from "normal" to "nebula," as the magnitude changed

* Monthly Notices, Vol. LII., pp. 357–368, March 1892. † *Ibid.*, Vol. LIII., p. 59.

‡ Proc. Roy. Soc., Vol. 68, p. 399.

§ Annals of Harvard College Observatory, XLVIII, Part. II., Plate I.

‖ Proc. Roy. Soc., Vol. 68, p. 403.

from maximum to minima respectively, until, on the latter date, it became constantly "nebula"; his "normal" spectrum is that which we have designated the bright-line spectrum.*

Nova Lacertæ showed similar light changes, but the oscillations recorded were neither so abrupt nor so frequent.†

In the case of Nova Geminorum (2) the primary fall from the initial maximum was of the same sudden nature as that observed in the case of Nova Persei, and there were numerous oscillations, roughly synchronous with changes in the spectrum, during the two months following the outburst. As will be seen from the light-curves plotted from the observations published by Dr. Freundlich,‡ the nova of 1911–12 did not exhibit the same regularity of period as shown by Nova Persei, but there is a general similarity. The curves shown on Plate III. have been plotted from the observations published by Prof. Pickering for Nova Persei (2), by Dr. Freundlich for Nova Geminorum (2), and Prof. Nijland for Nova Lacertæ.

Thus we see that the light-curves of probably all novæ observed during their early stages are of the same general character, in which an enormous outburst, frequently multiplying the emission of light many hundredfold, is followed by a very abrupt subsidence, which after a day or two becomes far more gradual and subject to slight periodical recoveries. The different times taken, in different novæ, for these changes to take place suggest that greatly differing masses, or velocities, are involved, while the rapid incandescence and subsidence in all cases point to the action of small individual masses and not to the collision of only two large bodies.

7.—LOCATION OF NOVÆ IN SPACE.

When considering the location of novæ in space we have to deal with two co-ordinates, the first giving us the distance from the solar system, the second the part of the apparent celestial sphere in which the nova appears.

For the first we have but a very meagre amount of data to work upon, for only in two cases has the object been near enough for its distance to be measurable with the present accuracy obtainable in parallax determinations. Nova Persei, in 1901, apparently offered the best opportunity, and the four values published, by different observers, vary from $+0{\cdot}16'' \pm 0{\cdot}06''$ (Hartwig) to $-0{\cdot}012'' \pm 0{\cdot}035''$; it is probable that the parallax did not exceed $0{\cdot}100''$.

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* Annals Harvard College Observatory, LVI., No. III., p. 62.

† Astronomische Nachrichten, No. 4562. (Prof. Nijland.)

‡ Astronomische Nachrichten, No. 4624.

An attempt to determine the parallax of Nova Lacertæ, 1910, made by Dr. Slocum, with the Yerkes 40-inch refractor, gave the value $+0''.013 \pm 0''.014$, and reducing this for the assumed parallax of the comparison stars a probable value, $+0''.018$, was obtained for the absolute parallax of the nova.*

Franz found a large negative value $-0''.32 \pm 0''.12$ for the nova† which appeared in the Andromeda nebula in 1885.

These results and those obtained for other novæ, only serve to point to the fact that, as a class, new stars are exceedingly remote from the solar system.

The second co-ordinate is much simpler to determine, depending only on direct observation of the nova's apparent position, and the result is very striking. All novæ, with the one exception of Nova Coronæ in 1866, have appeared in the Milky Way, its branches, or the Magellanic Clouds. This preference for the Galaxy is well shown for the northern hemisphere on Plate IV., where the positions of all northern novæ have been plotted on a photographic copy of Boeddicker's general map of the Milky Way. Such novæ as have appeared since 1891 are marked by the number given in Table I; those that appeared previously are marked by the name of the constellation and the date of their discovery.

ADDENDUM.

Subsequent to the completion of that part of the memoir dealing with the bright-line spectrum, and when the memoir was nearly ready for press, we received a paper by Prof. Adams and Mr. Kohlschutter discussing their observations of the spectrum of Nova Geminorum (2) at Mount Wilson.§

It was then too late to deal with this paper in the body of the memoir, but it is thought desirable to publish the following table, even without fuller discussion, comparing the lines and origins found by the Mount Wilson observers.

In the first column are given the wave-lengths. Messrs. Adams and Kohlschutter give a great number of wave-lengths for the separate parts of the bands, but in this table we have taken only such as are described as belonging to the centres of bright bands, *i.e.*, the typical bright bands of the "bright-line" stage. The second column contains the origins ascribed to these radiations. In the third and fourth columns we give the wave-lengths and origins found at South Kensington from the discussion of the Madrid spectrograms of the same nova. Then follow the similar data we published from this observatory in 1902,‡ in which it was shown that these bright radiations of

*Astrophysical Journal, Vol. XXXV., p. 137.

† Astronomische Nachrichten, No. 2816.

‡ Proc. Roy. Soc., Vol. 69, p. 356.

§ Astrophysical Journal, Vol. XXXVI., p. 293.

Nova Persei, other than those due to hydrogen, are chiefly due to proto-metallic substances, that is to say they are enhanced lines.

In the seventh column are given the wave-lengths of the corresponding enhanced lines and origins, and, speaking generally, they are the strongest enhanced lines, while finally we give the corresponding lines with their intensities in the spectrum of *α* Cygni.

The wave-lengths given by Messrs. Adams and Kohlschutter are the observed wave-lengths, and are subject to corrections for displacement which for the hydrogen lines H_ϵ, H_δ, H_γ and H_β are −1·3, −1·3, −1·8 and −1·8 tenth-metres respectively.

ADAMS'S AND KOHLSCHUTTER'S SPECTRUM OF NOVA GEMINORUM (2) COMPARED WITH THE SOUTH KENSINGTON RESULTS.

A. & K., Nova Geminorum (2).		S. Kensington, N. Geminorum (2).		S. Kensington, N. Persei (2).		S. Kensington, Enhanced Lines.		S. Kensington, *α* Cygni.			Remarks.
λλ Observed.	Origin.	λλ	Origin.	λλ	Origin.	λλ	Origin.	λλ	Int. Max. =10.	Origin.	
3891·3	H_ζ	—	—	3889	H_ζ	—	—	3889·1	10	H	
3955·2	—	—	—	—	—	3952·07	p. V	3952·1	1–2	p. V	
3970·7	H_ϵ	3969·2 3976·3	H_ϵ & Ca.	3969	H_ϵ & Ca	—	—	3968·6	10	H	
4035·0	--	—	—	—	—	4035·80	p. V	4035·8	2	p. V	
4067·9	Neb.	—	–	4067	p . Ni	4067·30*	p. Ni	4067·2	4	p. Ni	*Strongest enhanced line of nickel.
4086·6	—	4081·5	Reversal in dark H_δ	—	—	—	—	—	—	—	
4102·7	H_δ	4101·85	H	4102	H_γ	—	—	4101·8	10	H_δ	
4173·1	He*	4174·5	p. Fe	4175	p. Fe	4173·52 4178·95	p. Fe	4173·5 4179·0	6–7 6-7	p. Fe p. Fe	*He λ 4169.
4185·1	—	—	—	—	—	—	—	—	—	—	
4200·6	p. H	—	—	—	—	—	—	—	—	—	
4217·0	—	-	—	—	—	—	—	—	--	—	
4235·2	—	4232·5	p. Fe	4232	p. Fe	4233·25	p. Fe	4233·3	8	p. Fe	
4240·6	—	—	—	—	—	—	—	—	—	—	
4271·4	Neb.*	4267·2	—	—	—	4269·52	p. Cr	4269·8	1–2	p . Cr	*Nebular band λ4265.
4283·7	—	—	—	—	—	4284·38	p. Cr	4284·4	2	p. Cr	
4294·8	—	—	—	—	—	4294·20 4296·72	p. Ti p. Fe	4294·2 4296·7	4 4	p. Ti p. Fe	
4304·8	—	4301·1	p. Fe	4300	p. Fe p. Ti	4296·5 4303·31 } 4300·0 4300·21	p. Fe p. Ti	4300·2 4302·1 4303·3	5 2 5	p. Ti p.Ti p.Fe p. Fe	
4324·5	—	—	—	—	—	4321·20	p. Ti	4321·2 4326·0	2–3 3–4	p. Ti Unk.	
4342·6	H_γ	4340·66	H_γ	4341	H_γ	—	—	4340·7	10	H_γ	
4364·8	Neb.	—	—	—	—	—	—	—	—	—	
4386·0	He*	—	—	—	—	4385·55	p. Fe	4385·85	5–6	p. Fe	*He band at λ 4388.
4391·3	—	4392·3	—	4392	—	4391·19	p. Ti	4391·0	2-3	p. Ti	

ADAMS'S AND KOHLSCHUTTER'S SPECTRUM OF NOVA GEMINORUM (2), COMPARED WITH THE SOUTH KENSINGTON RESULTS—*continued.*

A. & K., Nova Geminorum (2).		S. Kensington, N. Geminorum (2).		S. Kensington, N. Persei (2).		S. Kensington, Enhanced Lines.		S. Kensington, α Cygni.			Remarks.
λλ Observed.	Origin.	λλ	Origin.	λλ	Origin.	λλ	Origin.	λλ	Int. Max. = 10.	Origin.	
—	—	—	—	4411	p. Ti	4411·20	p. Ti	4411·2	1	p. Ti	
4416·5	—	—	—	—	—	4417·0	*p. Fe	4417·0	5	p. Fe	*Fowler.
—	—	—	—	—	—	4417·88	p. Ti	4417·9	2–3	p. Ti	
—	—	—	—	4425	—	—	—	—	—	—	
—	—	4434·2	—	4434	—	—	—	4434·4	1	Unk.	
4442·6	He*	—	—	4444	p. Ti	4443·98	p. Ti	4444·0	4–5	p. Ti	*He band λ 4438.
—	—	4450·4	—	4454	—	—	—	—	—	—	
4473·3	He	4470·0	He	4470	p. Ti	4468·86	p. Ti	4468·7 4471·6	4 1-2	p. Ti He	
4520·1	—	4516·4	p. Fe	4519	p. Fe	4508·46 * 4515·51 4520·40 4522·69	p. Fe —	4520·4 4522·7	4 5	p. Fe p. Fe	*Mean λ = 4516·76
4522·8	—	—	—	—	—	—	—	—	—	—	
—	—	—	—	4535	p. Ti	4534·14	p. Ti	4534·1	5	p. Ti	
4552·4	—	4549·0	p. Fe	4548	p. Fe p. Ti	4549·64 4549·81	p. Fe p. Ti	4549·8	7	p. Fe p. Ti	
4579·4	—	—	—	—	—	4576·51	p. Fe	4576·5	3–4	p. Fe	
4586·0	—	4584·1	p. Fe	4583	p. Fe	4584·02	p. Fe	4584·0	7	p. Fe	
4601·0	—	—	—	—	—	—	—	—	—	—	
4611·7	Neb.	—	—	—	—	—	—	—	—	—	
4622·0	—	—	—	—	—	—	—	4623·5	< 1	Unk.	
4631·4	—	4633·1	p. Fe	4628	p. Fe	4629·50 * 4635·55	p. Fe	4629·6	5–6	p. Fe	*Mean λ = 4632·52
4640·7	Neb.	—	—	—	—	—	—	4641·1	< 1	Unk.	
4654·3	—	—	—	—	—	—	—	—	—	—	
—	—	4660·2	—	—	—	—	—	—	—	—	
4667·4	—	—	—	—	—	—	—	4667·2	2–3	Unk.	
4672·8	—	4674·7	—	4670	—	—	—	4673·5	< 1	Unk.	
4687·1	Neb.	4687	—	—	—	—	—	—	—	—	
4738·5	—	—	—	—	—	—	—	—	—	—	
4792·6	—	—	—	—	—	—	—	—	—	—	
4804·1	—	—	—	—	—	—	—	—	—	—	
—	—	—	—	4822	p. Cr	4824·33*	p. Cr	4824·3	4	p. Cr	*Strongest enhanced line of Cr
4837·2	—	—	—	—	—	—	—	—	—	—	
4841·7	—	—	—	—	—	—	—	—	—	—	
4842·9	—	—	—	—	—	—	—	—	—	—	
4863·0	Hβ	4861·49	Hβ	4862	Hβ	—	—	4861·49	10	Hβ	
4905·4	—	No record beyond Hβ		—	—	—	—	—	—	—	

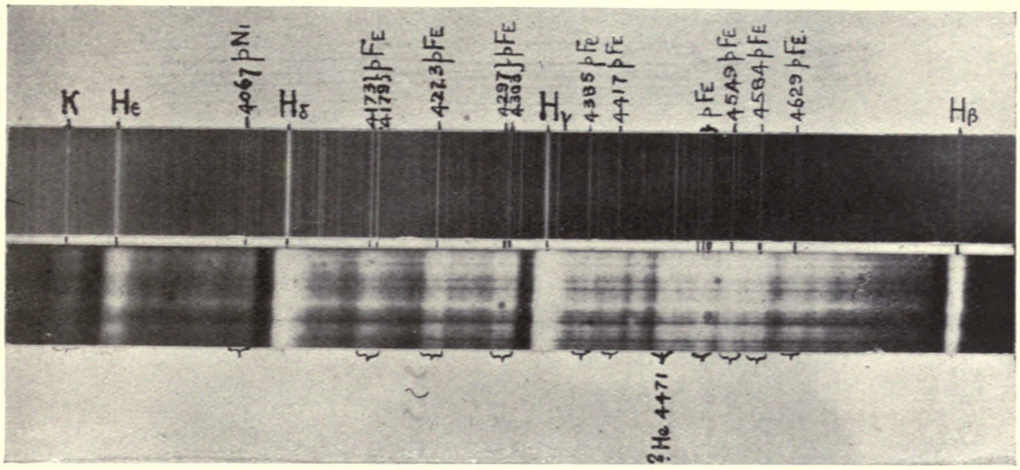
ADAMS'S AND KOHLSCHUTTER'S SPECTRUM OF NOVA GEMINORUM (2), COMPARED WITH THE SOUTH KENSINGTON RESULTS—*continued.*

A. & K., Nova Geminorum (2).		S. Kensington, N. Geminorum. (2).		S. Kensington, N. Persei (2).		S. Kensington, Enhanced Lines.		S. Kensington, *a* Cygni.			Remarks.
λλ Observed.	Origin.	λλ	Origin.	λλ	Origin.	λλ	Origin.	λλ	Int. Max. = 10.	Origin.	
4925·8	? He	—	—	4924	p. Fe	4924·11	p. Fe	4924·1	8	p. Fe	
4959·0	Neb.	—	—	—	—	—	—	—	—	—	
4992·8	—	—	—	—	—	—	—	—	—	—	
5007·0	Neb.	—	—	—	—	—	—	—	—	—	
5019·3	? He	—	—	5019	p. Fe	5018·63	p. Fe	5018·6	7	p. Fe	
5048·7	He	—	—	—	—	—	—	{ 5042·0 5057·0	4 5 }	p. Si (II.).	
5172·5	Mg*	—	—	5169	p. Fe†	{ 5169·07 5169·22 }	p. Fe	5169·2	6	p. Fe	*Mg. *b* group.
5239·0	—	—	—	—	—	—	—	—	—	—	
5279·0	—	—	—	—	—	5276·17	p. Fe	5276·2	3–4	p. Fe	
—	—	—	—	—	—	—	—	5279·5	1-2	Unk.	
5319·4	—	—	—	5316	p. Fe	5316·79	p. Fe	5316·8	6	p. Fe	
5379·1	—	—	—	—	—	—	—	—	—	—	
—	—	—	—	5420	—	—	—	—	—	—	
—	—	—	—	5475	—	—	—	—	—	—	
—	—	—	—	5530	p. Sc	5527·03*	p. Sc	—	—	—	* Strongest spark line of Sc. in the visual region.
—	—	—	—	5575	—	—	—	—	—	—	
5580·4	—	—	—	—	—	—	—	—	—	—	
5680·8	—	—	—	—	—	—	—	—	—	—	
—	—	—	—	5686	—	—	—	—	—	—	
5757·3	—	—	—	—	—	—	—	—	—	—	
5877·9	—	—	—	5893	Na*	—	—	—	—	—	*D.
5942·3	—	—	—	—	—	—	—	—	—	—	
6004·8	—	—	—	No record beyond D.		—	—	—	—	—	
6158·8	—	—	—	—	—	—	—	—	—	—	
6248·8	—	—	—	—	—	—	—	—	—	—	
6302·4	Neb.	—	—	—	—	—	—	—	—	—	
6367·6	—	—	—	—	—	—	—	—	—	—	
6474·1	—	—	—	—	—	—	—	—	—	—	
6486·5	—	—	—	—	—	—	—	—	—	—	
6536·9	—	—	—	—	—	—	—	—	—	—	
6567·0	—	—	—	—	—	—	—	—	—	—	
6677	He	—	—	—	—	—	—	—	—	—	

† In the S. Kensington publication of 1902 it was remarked of this λ 5169 line, "Certainly not the *b*-group of magnesium."

PLATE I.

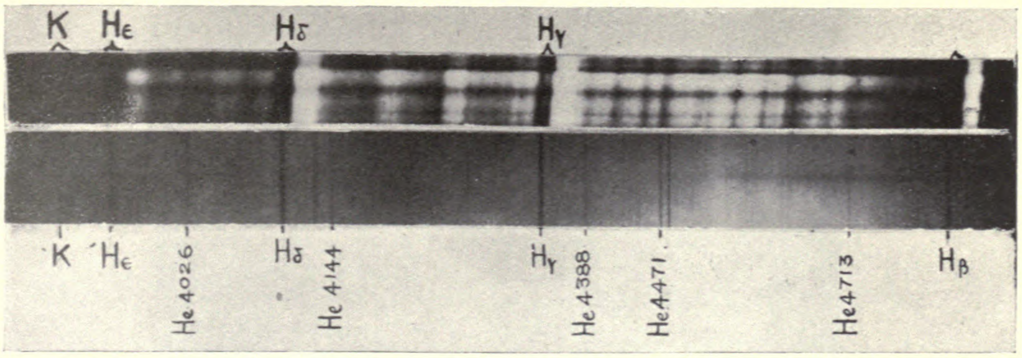
1912,
Mar. 24.



a Cygni, Kensington (negative).

Nova Geminorum, Madrid (positive).

1912
Mar. 22,

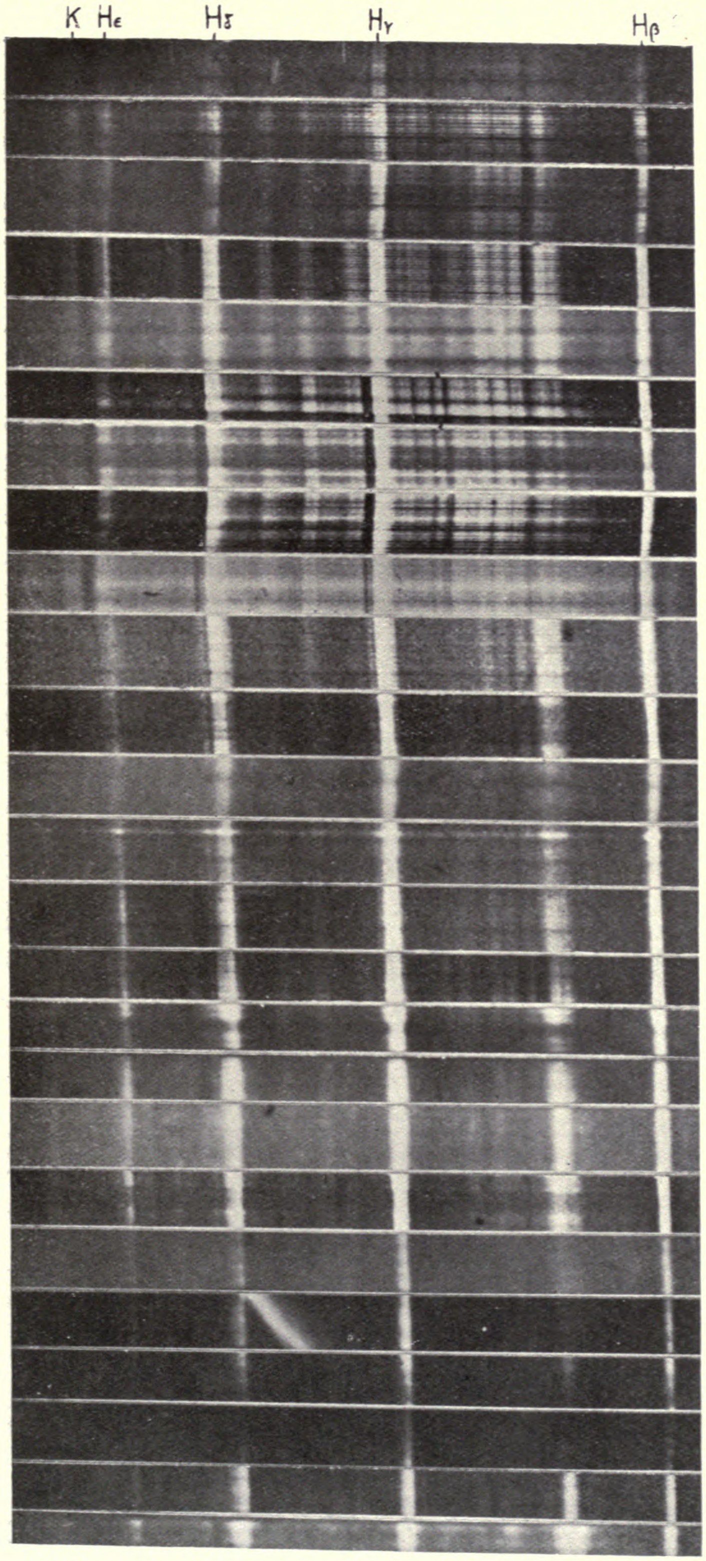


Nova Geminorum, Madrid.

Rigel. Kensington.

Comparison of Nova Geminorum Spectrum (Madrid) with the typical Spectra of the Cygnian and Rigelian groups (S. Kensington).

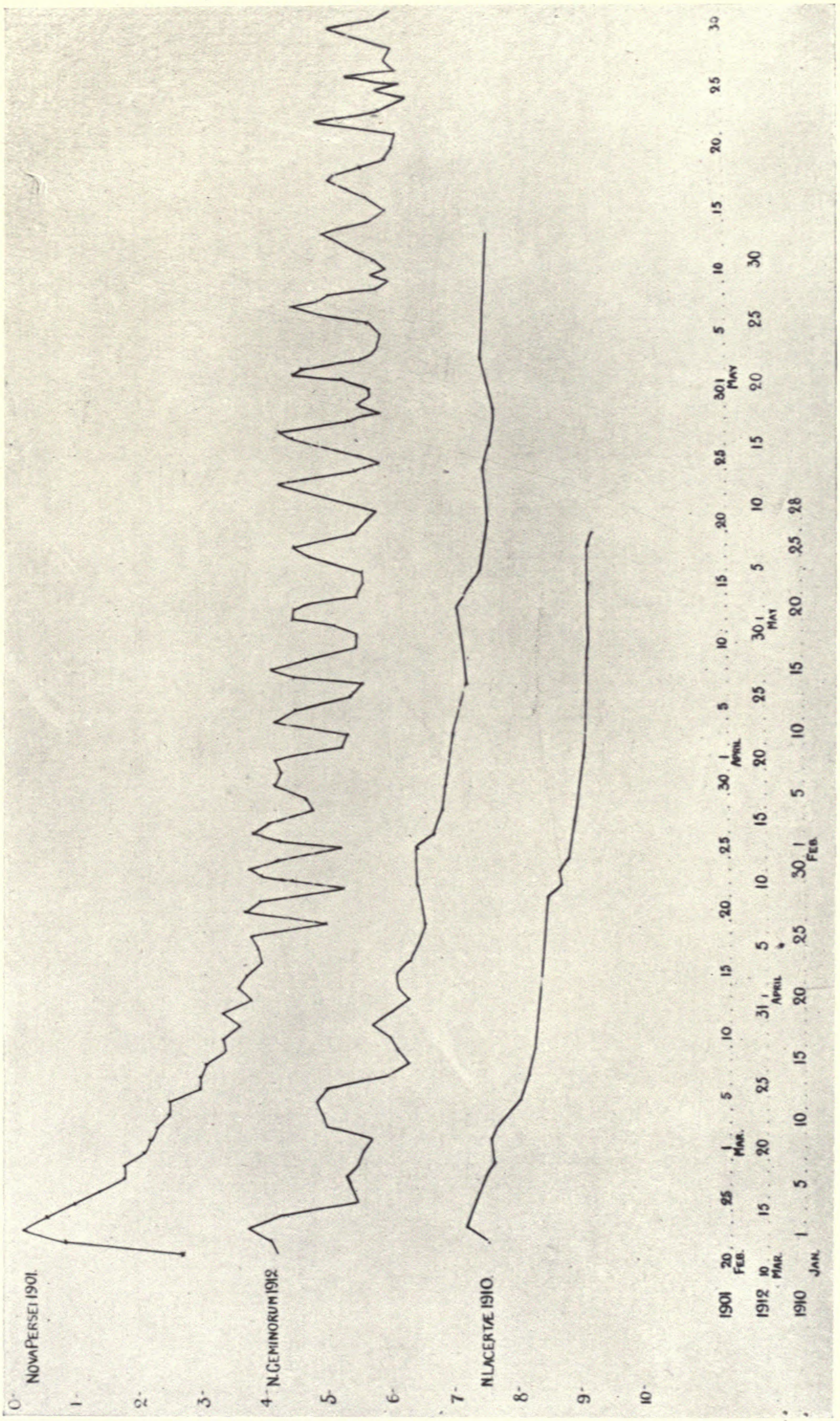
PLATE II.



1912.
Mar. 16
„ 17
„ 18
„ 19
„ 20
„ 22
„ 23
„ 24
„ 25
„ 27
„ 28
„ 29
Apr. 1
„ 2
„ 3
„ 4
„ 5
„ 6
„ 7
„ 8
„ 9
„ 10
„ 13
„ 15
„ 16

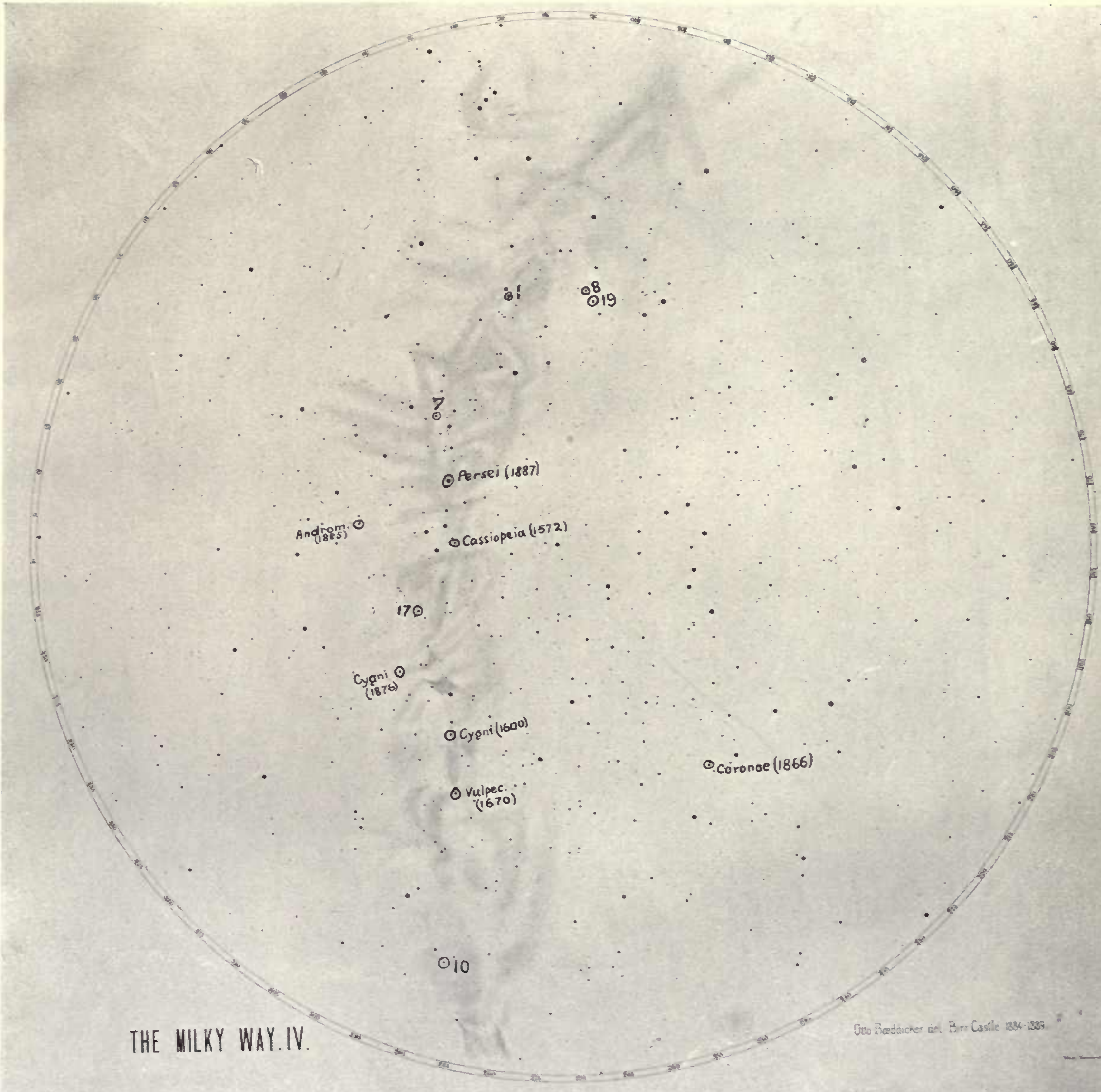
Nova Geminorum (2), Madrid Spectra.

PLATE III.



COMPARISON OF THE LIGHT-CURVES OF NOVÆ.

PLATE IV.



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